CLIMATE *READY* BOSTON

FINAL REPORT

MAYOR MARTIN J. WALSH

DECEMBER 2016

December 2016

Dear Neighbors,

The challenge of climate change is here, in Boston, now. We've seen more frequent flooding on Morrissey Boulevard. We endured the record-setting snowstorms of 2015. And this year we experienced the driest, and one of the hottest, summers in our history. Climate change has influenced all these events. I've felt these changes from my home in Dorchester, and I know you've felt them in your neighborhoods, too.

As the century progresses, the effects of climate change will grow. Those changes might seem overwhelming, but Bostonians are practical and creative. We work together to solve problems. And our response to climate change is no exception. Climate change has been a top priority since I entered office. All parts and sectors of the city have expanded their efforts to save energy and reduce greenhouse gas emissions, the cause of climate change. Now, because we know that the climate will continue to change for many years, we—with community organizations, academic institutions, and businesses—are accelerating the work of preparing Boston for change that cannot be avoided.

A year ago, with the support of the Commonwealth of Massachusetts and the Green Ribbon Commission, I launched Climate Ready Boston, an initiative to create a systematic and comprehensive framework for the work we must do. With a team that included local climate scientists and experienced engineers, planners, and designers, Climate Ready Boston updated the projections of how much our climate will change, identified where we're most vulnerable, and proposed steps for becoming more resilient to the changes ahead. I'm pleased to share the results with you.

Our responsibility is to turn these proposals into action. Climate change is not a narrow issue, but one that affects the social and economic vitality of our city. Climate action will not only keep us safer in the face of higher tides, more intense storms, and more extreme heat. It will also create jobs, improve public spaces and public health, and make our energy supply more efficient and resilient. These improvements will provide long-term economic benefits, strengthen our infrastructure, and make our neighborhoods safer. By preparing for the inevitable effects of climate change as part of the Imagine Boston 2030 citywide plan, we're investing in our future.

Climate change poses a greater threat to some Bostonians. The very young and very old, people who do not speak English, and those with low incomes or medical illnesses or disabilities are all at elevated risk. By ensuring that our solutions are built together with those communities and in response to their needs, climate action will help us build a more equitable city. Furthermore, because climate change knows no borders, we will work with neighboring municipalities to address the regional impacts we face together.

Climate change will continue for decades. Today, we can take steps to make our city healthier and more thriving now and establish a foundation that enables the next generation to build on the work that we are starting. I look forward to working with you in your communities.

Sincerely,

Martin J. Walsh, Mayor

The City of Boston and Green Ribbon Commission would like to thank the following individuals and groups for their contributions to Climate Ready Boston.

CLIMATE READY BOSTON STEERING COMMITTEE

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Boston Water and Sewer Commission
Boston Public Schools
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Boston Landmarks Commission
Boston Office of Emergency Management
Boston Parks and Recreation Department
City of Cambridge

State and Regional
MA Department of Conservation and Recreation
MA Department of Public Utilities
MA Department of Transportation
Metropolitan Area Planning Council
Massachusetts Bay Transportation Authority
Massachusetts Port Authority
Massachusetts Water Resources Authority
National Park Service (Harbor Islands)

Utilities
Comcast
Eversource Energy
National Grid
Veolia
Verizon Communications

Nonprofit
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A Better City
Partners Health Care
The Trust for Public Land
The Trustees of Reservations
Boston University
Harvard University
Green Ribbon Commission Climate Preparedness Working Group

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Boston Housing Authority
Boston Public Health Commission
Mayor's Office of Resilience and Racial Equity
Mayor's Office for Immigrant Advancement

Nonprofit
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Boston Climate Action Network
Boston Harbor Now
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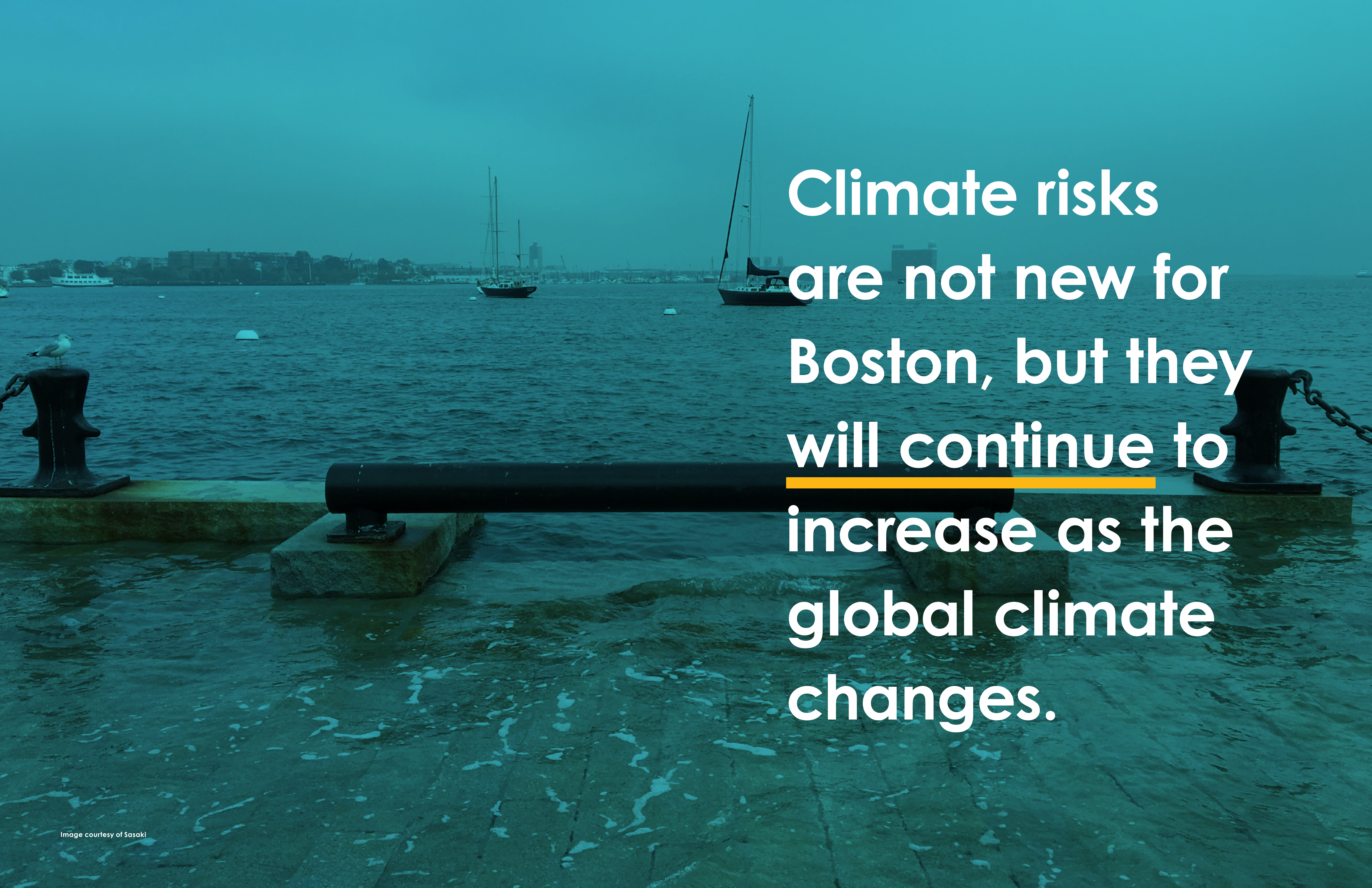


Image courtesy of Sasaki

Climate risks are not new for Boston, but they will continue to increase as the global climate changes.

Since 1991, Boston has experienced 21 events that triggered federal or state disaster declarations.

For example, in 2011, Hurricane Irene caused downed trees and power outages across the city. In 2012, while Boston was spared the most devastating effects of Hurricane Sandy due to the storm missing Boston's high tide by five hours, the city still experienced high winds and coastal flooding. As the climate changes, the likelihood of coastal and riverine flooding—as well as other hazards, like stormwater flooding and extreme heat—will increase.

The challenges from climate change are substantial and complex but can be addressed through bold and creative actions that support the city's vitality and livability.

Boston can thrive in the coming decades if it takes action to adapt its people, its neighborhoods, and its economic and cultural assets, starting now. This work will be difficult, contentious, and complex. But if done well, it will not only create a resilient, climate-ready Boston—it will also dramatically improve the city and quality of life for all its residents.

Boston can thrive in the coming decades if it takes action to adapt its people, its neighborhoods, and its economic and cultural assets, starting now.

Image courtesy of Sasaki

To address these challenges, **Climate Ready Boston** features four components.

UPDATED CLIMATE PROJECTIONS

A set of updated projections for four climate factors: extreme temperatures, sea level rise, extreme precipitation, and storms. The University of Massachusetts Boston oversaw a team of climate scientists, the Boston Research Advisory Group, to develop these projections.

CLIMATE FACTORS

- Extreme Temperatures
- Sea Level Rise (SLR)
- Extreme Precipitation
- Storms

VULNERABILITY ASSESSMENT

A comprehensive evaluation of current and potential future risks associated with each of three climate hazards (extreme heat, stormwater flooding, and coastal and riverine flooding) for Boston's people, buildings, infrastructure, and economy. Vulnerability assessment data for the three climate hazards reflects the underlying factors studied in the Climate Projection Consensus.

VULNERABILITY ASSESSMENT HAZARDS

- Extreme Heat
- Stormwater Flooding
- Coastal and Riverine Flooding

FOCUS AREAS

Eight Boston areas where the results of the Vulnerability Assessment and the climate resilience initiatives are applied in more detail to illustrate the risks Boston faces and how Boston can address them. The focus areas recognize that some risk, particularly for coastal and riverine flooding, is spatially concentrated.

ANALYSIS AREAS

- Charlestown
- Charles River
- Dorchester
- Downtown
- East Boston
- Roxbury
- South Boston
- South End

CLIMATE RESILIENCE INITIATIVES

These policy, planning, programmatic, and financial initiatives address the risks identified in the Vulnerability Assessment and work together to increase Boston's resilience. The initiatives are summarized in an Implementation Roadmap that sets forth, for each initiative, responsibility, time frame, and key milestones.

INITIATIVE LAYERS

- Updated Climate Projections
- Prepared and Connected Communities
- Protected Shores
- Resilient Infrastructure
- Adapted Buildings

Climate Ready Boston is coordinated with Imagine Boston 2030, the first citywide plan in 50 years, and 100 Resilient Cities, to guide Boston toward a more affordable, equitable, connected, and resilient future.

Through Imagine Boston 2030, the City has identified areas that have capacity to accommodate Boston's growing population and dynamic economy. Many of the areas where Boston will grow will be exposed to increasing flood risk as sea levels rise. As it grows in these areas, Boston is committing to protecting them. While we do not know all the mechanisms for protection yet, Boston is investing in developing local climate resilience plans for vulnerable areas. These plans will identify multilayered investments needed to enable climate-ready growth.

Boston will approach this topic dynamically and respond to new information as we have it. Climate adaptation presents Boston with opportunities for carefully managed growth and investment that ensure existing neighborhoods can thrive, new neighborhoods are ready for the changing climate, and jobs are created and expertise developed for long-term growth and protection.

PLANNING CONTEXT

Boston's favorable location, with three rivers flowing into a sheltered harbor well-suited for waterborne trade, helped it grow into a major commercial city. The city's core was once the narrow Shawmut Peninsula, but as trade and population grew to make Boston the economic center of the region, Bostonians filled in the tidal marshes with wharves, parks, and entire neighborhoods built on new land. In the three centuries following Boston's founding in 1630, the city's footprint increased by nearly 50 percent, with much of the land along the coastline and riverbanks filled to just above high tide.

Although coastal expansion in previous centuries made the city more vulnerable to climate change, it helped Boston become the largest residential and commercial center in New England. The city is home to over 656,000 residents[1] and 718,000 jobs,[2] accounting for a total of $160 billion in annual economic output. Boston is a center for financial institutions, higher education, and medical services. It is also the hub of the region's transportation system, with subway lines, bus service, commuter rail lines, ports, and Logan International Airport.

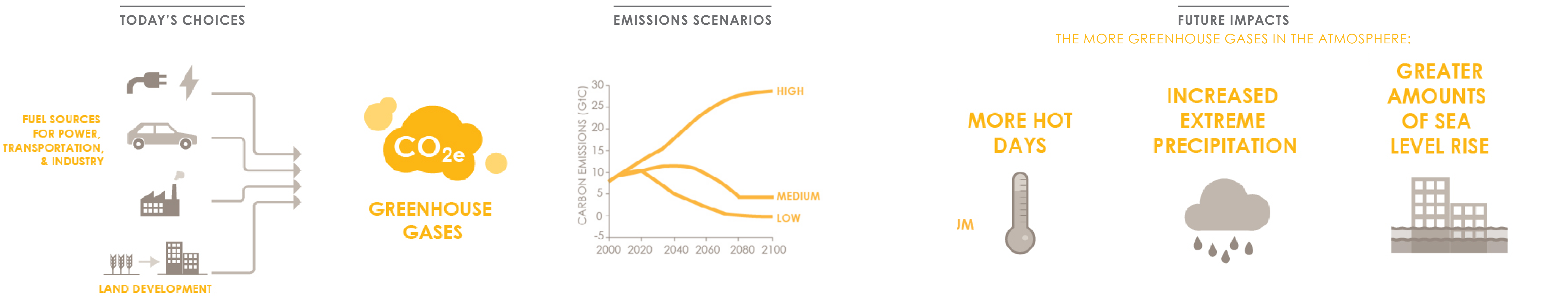
Boston recognized the threat of climate change early and has pursued an integrated approach to address it. In 2000, Boston launched its climate action program when it joined the Cities for Climate Protection Campaign of ICLEI-Local Governments for Sustainability. Over the last 15 years, the City has led a range of efforts to reduce emissions citywide to slow the pace and scale of climate change, including the 2011 commitment for an 80 percent reduction in carbon emissions by 2050. In recognition of these efforts, the City received an award at the United Nations Climate Change Conference in Paris (COP21). However, even under the most optimistic projections of global emissions reductions, Boston faces serious risk from climate change and must adapt.

ABOVE
Boston's Present & Historical Shoreline

Climate Ready Boston will guide Boston's adaptation efforts, building upon recommendations from the City's 2007 Climate Action Plan and its 2011 and 2014 updates. Based on the most up-to-date scientific consensus of future climate conditions, Climate Ready Boston provides an evaluation of potential impacts from Boston's three major climate hazards: extreme heat, stormwater flooding, and coastal and riverine flooding. Climate Ready Boston then identifies climate resilience initiatives to enable Boston to address these risks and continue to thrive in the face of climate change.

[1] Source: "ACS 5-Year Estimates (2011–2014)." U.S. Census Bureau.
[2] Source: Boston Planning and Development Agency Analysis.

Boston's Future Climate



Bostonians must first understand the likely impacts of climate change in order to plan for a strong, resilient future.[3]

To help us understand climate change impacts at the local level, Climate Ready Boston convened a working group of the region's climate scientists. The Boston Research Advisory Group (BRAG), overseen by the University of Massachusetts Boston School for the Environment, developed this consensus about how Boston's climate will change over the course of the twenty-first century.

The longer-term impacts of climate change are largely dependent on the global community's success at curbing emissions of greenhouse gases. Because we do not know how well we will do, scientists use multiple emissions scenarios as the bases for their projections. Climate projections for the next few decades are relatively consistent, regardless of which emissions scenario they rely on. However, the projections become increasingly different the further we look into the future.

Climate Ready Boston's climate projections use three emissions scenarios from the Intergovernmental Panel on Climate Change:

- **A HIGH-EMISSIONS SCENARIO** often characterized as a continuation of *business as usual;*
- **A MEDIUM-EMISSIONS SCENARIO** in which emissions remain around their current levels through 2050 and then are slowly reduced in the second half of the century through *moderate emissions reductions and;*
- **A LOW-EMISSIONS SCENARIO** in which net global emissions are reduced to less than a third of their current levels by 2050 and are brought to zero by about 2080 through *major emissions reductions.*

These findings emphasize that a critical strategy for climate adaptation is the expansion of efforts to reduce our carbon emissions.

[3] This section is a summary of the BRAG Climate Projection Consensus report, which describes future climate conditions in the Boston region, including extreme temperatures, sea level rise, heavy precipitation, and coastal storms. The full report is available at climateready.boston.gov/findings.

EXTREME TEMPERATURES

Average temperatures in the Northeast have been slowly rising for over a century. Temperatures in the northeastern United States increased by almost two degrees Fahrenheit between 1895 and 2011.

The rate of increase in average temperatures is accelerating, and Boston's average summer temperatures and number of days with extreme heat will increase. Heat waves will become more common, last longer, and be hotter. While the average summer temperature in Boston from 1981 to 2010 was 69 degrees, it may be as high as 76 degrees by 2050 and 84 degrees by 2100. In other words, by 2050 Boston's summers may be as hot as Washington, DC's, summers are today, and by the end of the century, they may be hotter than Birmingham, AL are today. Compared to the period from 1971 to 2000, when there were 11 days per year over 90 degrees, there may be as many as 40 by 2030 and 90 by 2070—nearly the entire summer. Heat waves—extended periods of extreme heat—are a leading cause of weather-related mortality in the United States.

Although winters will be warmer, the risk of frost and freeze damage and cold snaps will continue. While from 1981 to 2010, Boston reached below freezing almost one out of three days per year, by the end of the century, this may happen only around one in ten days.

As an urban area, Boston tends to be hotter than surrounding communities that are more suburban or rural. Urban areas generally tend to be hotter than nearby rural areas because concrete, steel, and other building materials retain more heat than vegetation. This phenomenon, known as the "urban heat island effect," is compounded by climate change.

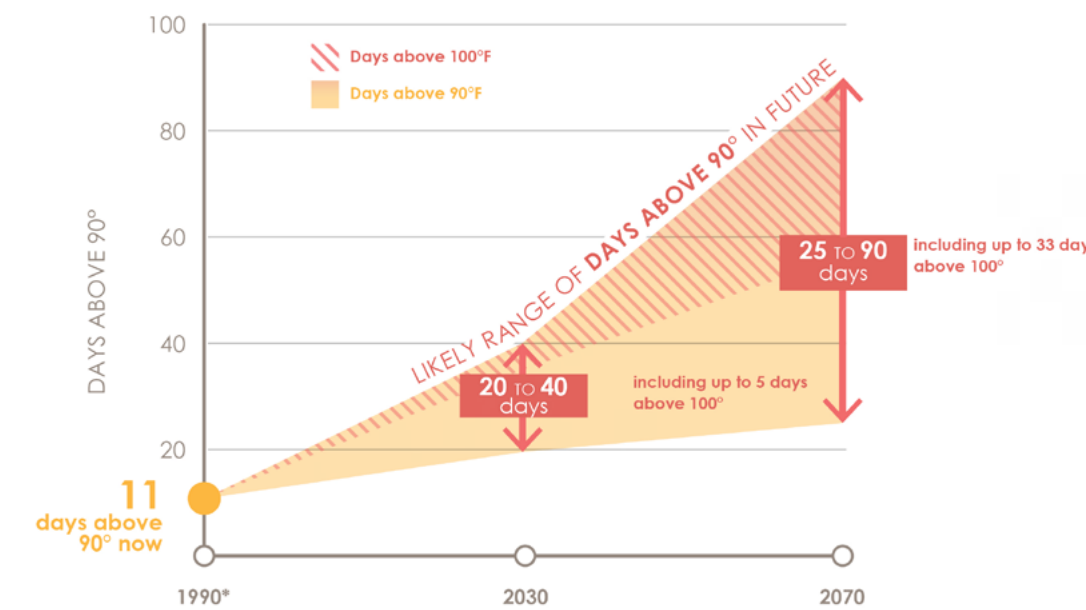
Future temperatures in Boston will depend on how much we are able to cut our greenhouse gas emissions. The rise in temperatures between now and 2030 is largely consistent between all emission scenarios. However, the scenarios show that cutting emissions now can greatly slow the rise in temperatures in the second half of the century.

SEA LEVEL RISE

The pace of relative sea level rise is accelerating. Over the entire twentieth century, sea levels rose about nine inches relative to land. Another eight inches of relative sea level rise may happen by 2030, almost three times faster. By 2050, sea levels may be as much as 1.5 feet higher than they were in 2000, and by 2070, they may be as much as 3 feet higher than in 2000. This is driven by a combination of the melting of land ice, the expansion of water as it warms, and changes in the amounts of water extracted from below ground or stored behind dams.

A major reduction in global greenhouse gas emissions can have a tremendous impact on the future of Boston Harbor. While sea level rise projections for 2030 are about the same across all emission scenarios, in later years there are big differences between scenarios. With a sharp reduction in global emissions, end-of-century sea level rise could stay under two feet, but a continuation of business as usual may result in over seven feet of sea level rise.

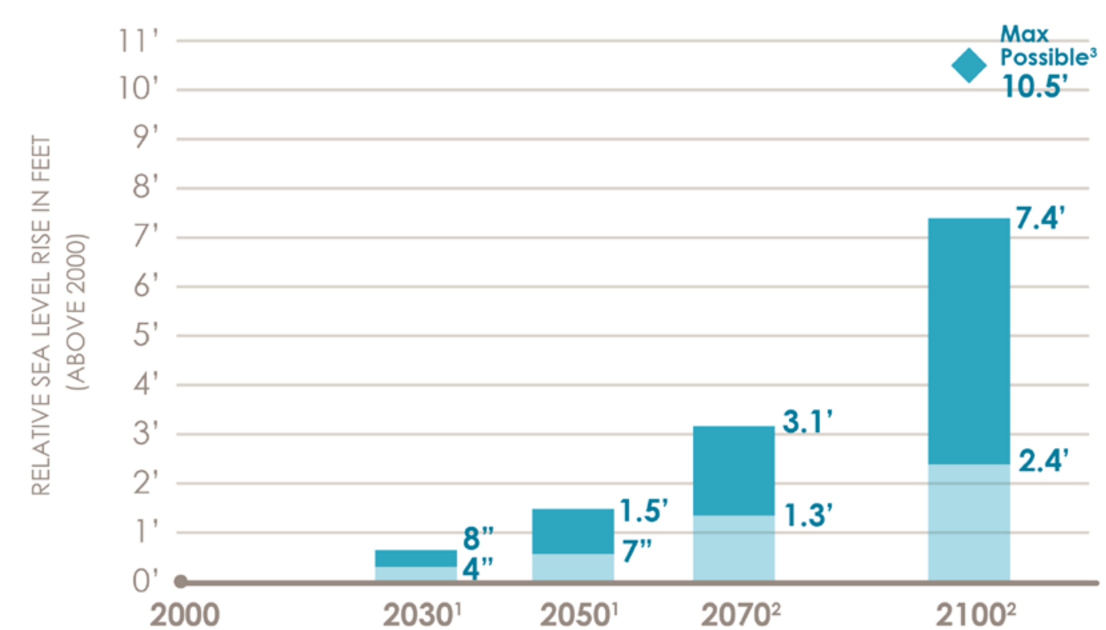
THE NUMBER OF VERY HOT DAYS WILL INCREASE



Data source: Rossi et al. 2015

* Baseline represents historical average from 1971-2000
Upper values from high emissions scenario. Lower values from low emissions scenario.

SEA LEVELS IN BOSTON WILL CONTINUE TO RISE



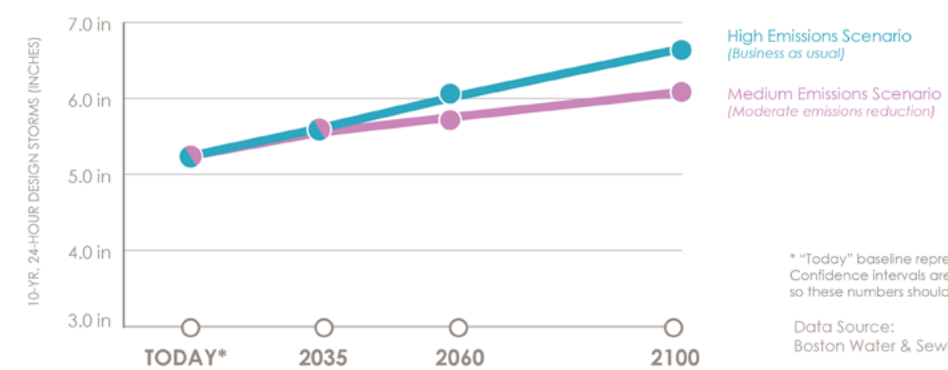
Data Source: BRAG Report, 2016

1 - Likely under all emission scenarios
2 - Likely under moderate to high emission scenarios
3 - Low probability under high emission scenario

Image courtesy of Sasaki

Rising sea levels mean that **any given storm** will cause more flooding in the future than it would today.

RAINFALL FROM STORMS WILL INCREASE



* "Today" baseline represents historical average from 1948-2012
Confidence intervals are not available for these projections but are likely large, so these numbers should be considered as the middle of a large range

Data Source:
Boston Water & Sewer Commission

EXTREME PRECIPITATION

In the Northeast, there has already been a very large increase in the intensity of extreme rain and snow. From 1958 to 2010, there was a 70 percent increase in the amount of precipitation that fell on the days with the heaviest precipitation. This increase is greater in the Northeast than for any other region of the country.

The increase in extreme precipitation is expected to continue. As the climate warms, more ocean water evaporates into the air, and warmer air can hold more water, supporting heavier precipitation events. Heavy precipitation events will continue to increase in Boston. However, due to the complexity of the processes underlying precipitation as well as natural variability, the magnitude of this increase is not yet clear.

If we take action to cut global greenhouse gas emissions, we can prevent the most extreme precipitation projections from becoming a reality. A commonly used measure of major rain and snow events is the "10-year, 24-hour storm," or the amount of precipitation that has at most a one-in-ten annual chance of falling during a 24-hour period. While projections for these events are similar in the short term across different emissions scenarios, by the end of the century, the difference between medium and high scenarios is about 10 percent.

STORMS

Current climate projections do not provide a clear projection of how the intensity, frequency, and trajectory (tracks) of tropical and extratropical storms will change. Extratropical storms (like blizzards and nor'easters) have cold air at their centers. Tropical storms, on the other hand, have warm air, which means that they can develop into hurricanes more quickly. There are large uncertainties about how climate change will affect future storms. This is particularly true for extratropical storms. For tropical storms, there is some evidence that their intensity has been increasing. If tropical storm intensity increases, there could be more frequent major hurricanes (Category 3 and greater), even if the total number of tropical storms does not increase.

Rising sea levels mean that any given storm will cause more flooding in the future than it would today. During a storm, winds can blow ocean water towards the land, creating a "storm surge" on top of the baseline sea level. When storm surge is combined with tidal processes, the result is known as a "storm tide." With higher seas, it takes less precipitation and a less powerful storm surge to produce the same amount of flooding as a more powerful storm would produce when the seas are lower.

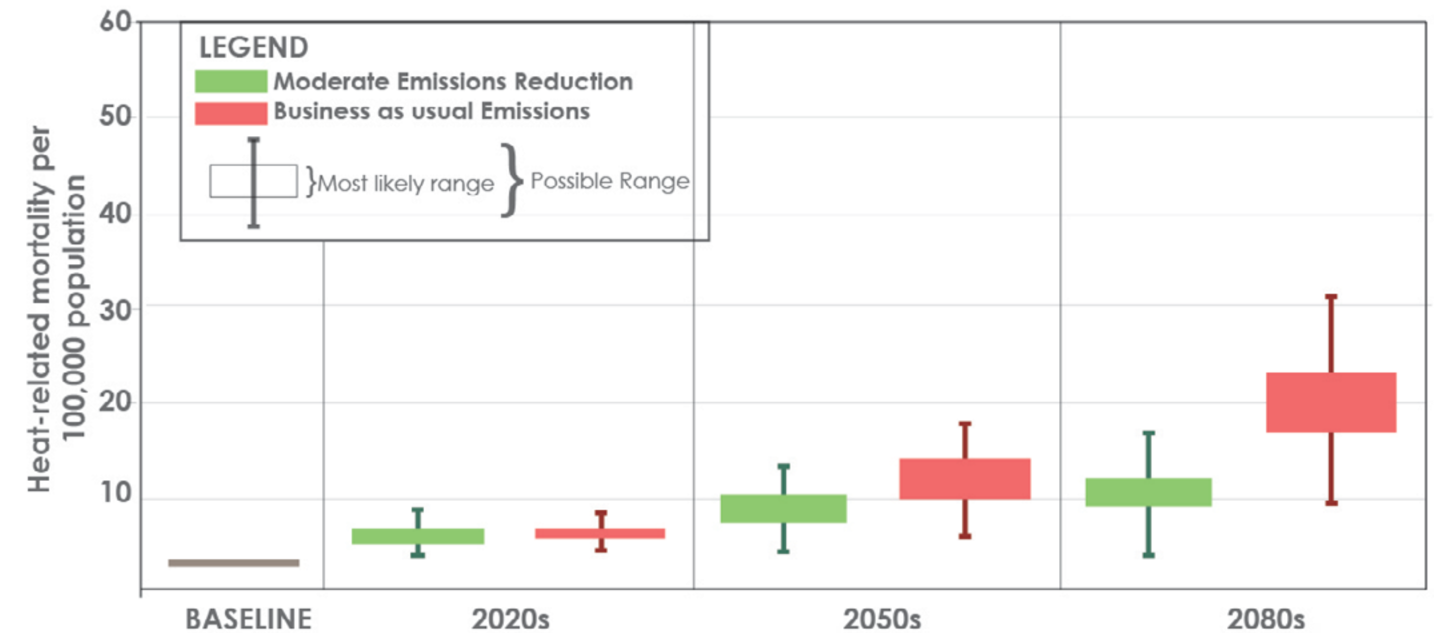
Boston's Increasing Climate Vulnerability

Image courtesy of Sasaki

The Vulnerability Assessment analyzes how Boston's people, buildings, infrastructure, and economy will be affected by climate hazards.

In considering the impacts on people, the assessment focuses on socially vulnerable populations, people who are more vulnerable to climate hazards because they already experience stressors, such as poverty, poor health, and limited English proficiency. For property, the assessment considers direct and indirect impacts, in terms of both structural damage to buildings and site-access challenges. For infrastructure, it analyzes expected impacts on Boston's transportation, power, water and sewer, emergency response, and environmental systems. Finally, it evaluates the potential economic impacts of flooding, such as the loss of jobs and disruption of business operations.

THE NUMBER OF HEAT-RELATED DEATHS EACH YEAR IN BOSTON WILL TRIPLE

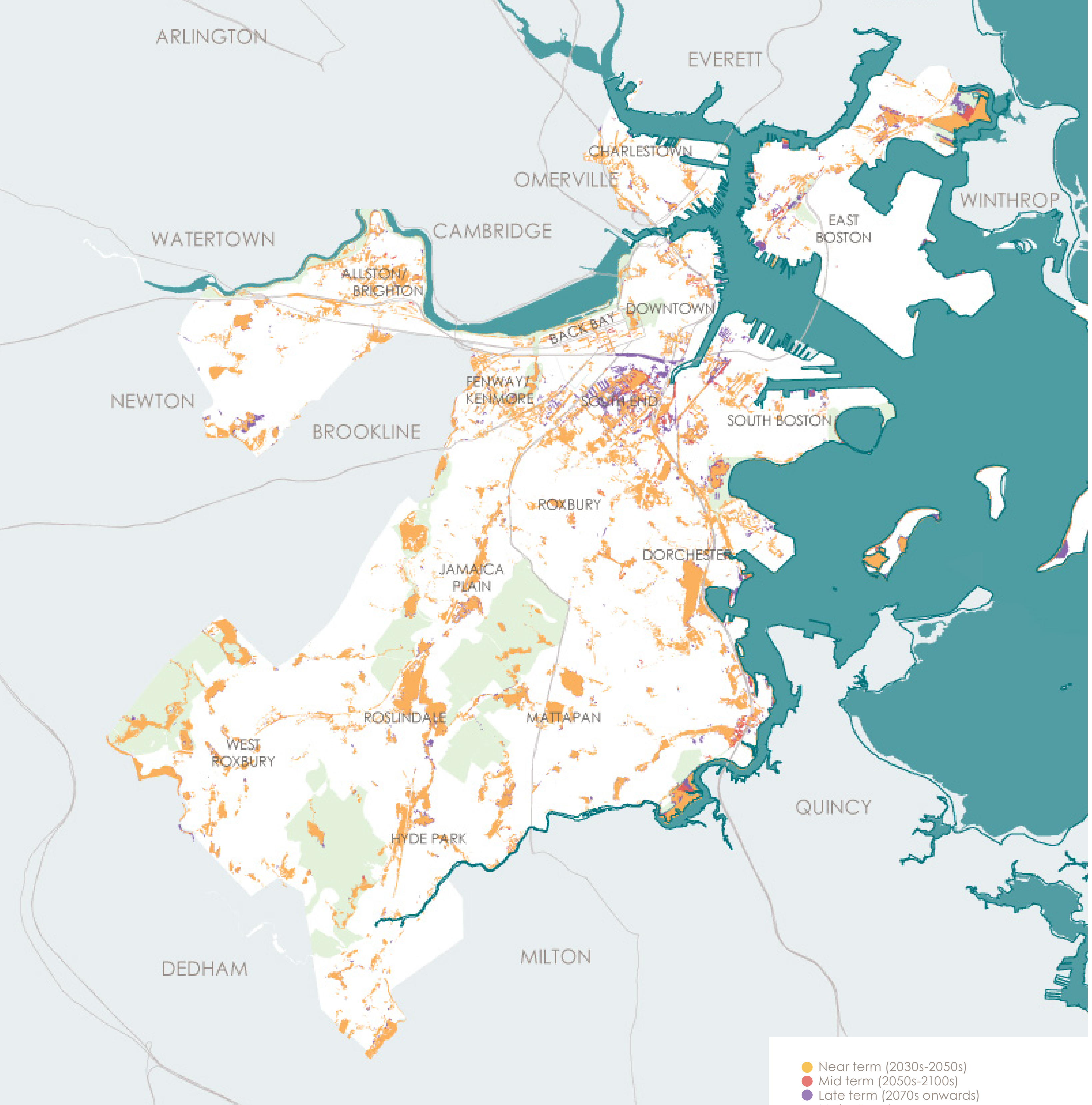


EXTREME HEAT IMPACTS

With climate change, Boston will experience both increasing average temperatures and increasing frequency, duration, and intensity of heat waves. While temperatures are hottest in areas of the city that experience localized urban heat island effects, on very hot days, the entire city is at risk for the negative impacts of extreme heat.

Extreme heat can cause negative health impacts, including direct loss of life, increases in respiratory and cardiovascular diseases, and challenges to mental health. In the baseline period (1985 to 2016), the heat-related mortality rate was about 2.9 per 100,000 people in Boston. During the 2020s, this rate is expected to more than double. By the 2080s, this rate may more than triple to 10.5 per 100,000 people under a moderate emissions reduction scenario or reach as high as 19.3 per 100,000 under the business-as-usual emissions scenario. Climate change can also harm air quality, leading to increasing risks for diseases such as asthma. Health impacts will be especially significant for populations such as older adults, children, and the medically ill.

Heat can have negative consequences for Boston's infrastructure, presenting further challenges for health and quality of life. Power failures are more likely during heat waves due to the increased demand for electric power for air conditioning, as well as the added stress of the heat on mechanical and electrical assets. High temperatures can also cause thermal expansion in roads and railroad tracks, leading to damage or requiring speed reductions. As rising temperatures lead to a potential increase in tree mortality, any loss of canopy coverage or green space will only contribute to the urban heat island effect, reduced air quality, increased stormwater runoff, and decreased quality of life.



STORMWATER FLOODING FROM 10-YEAR, 24-HOUR STORM WITH VARYING CLIMATE CONDITIONS

Without improvements to the stormwater system, over 11,000 structures and 85,000 people will be directly exposed to frequent stormwater flooding as soon as the 2070s.[4]

[4]Current building stock and population in areas expected to be exposed. The building stock and population have not been projected.

STORMWATER FLOODING IMPACTS

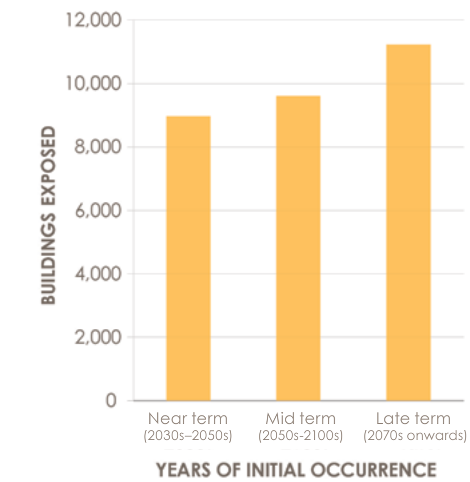
Stormwater flooding occurs throughout Boston today, as the city's drainage system struggles to manage intense rain events, rising sea levels, and less permeable ground surface that would slow and absorb stormwater. Common areas for stormwater flooding are along the coast, where outfalls may be unable to discharge; transportation corridors with impervious surfaces where water cannot percolate; and designed drainage areas whose capacities are exceeded. The drainage system requires ongoing investments to catch up and keep up with climate conditions.

In the near term (2030s–2050s), rising sea levels and increasing extreme precipitation will exacerbate stormwater flooding, unless the drainage system is upgraded. Higher sea levels mean that stormwater outfalls may not be able to discharge or may even backflow, and more extreme precipitation means that drains and pipes must handle greater volumes of water in short periods of time.

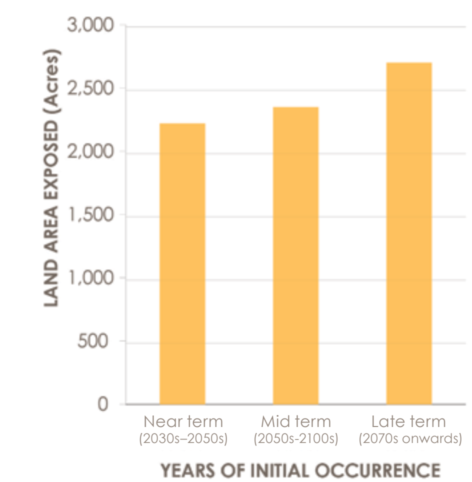
The area of Boston exposed to stormwater flooding is projected to grow steadily throughout the century. As soon as the 2050s, 7 percent of the total land area in the city could be exposed to frequent stormwater flooding from 10-year, 24-hour rain events.

Transportation infrastructure will be impacted by frequent stormwater flooding at multiple scales ranging from sidewalks to local streets to major thoroughfares like highways and MBTA lines. Frequent stormwater flooding is projected near major thoroughfares such as Columbus Avenue, Tremont Street, and Morrissey Boulevard, as well as Interstates 90 and 93 and along the MBTA Orange and Red Lines. Additionally, many of these transportation routes are also designated evacuation routes, which may become increasingly more flood prone to coastal storms with heavy rainfall.

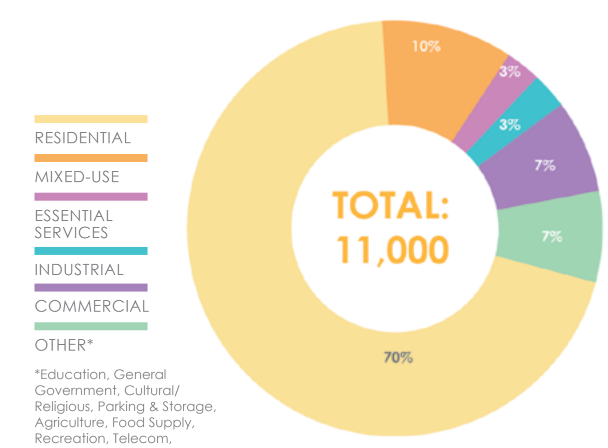
BUILDINGS EXPOSED TO FREQUENT STORMWATER FLOODING



LAND AREA EXPOSED TO FREQUENT STORMWATER FLOODING



BUILDINGS EXPOSED TO FREQUENT STORMWATER FLOODING TYPE (2070S-2100S)



COASTAL & RIVERINE FLOODING IMPACTS

What Is a "1 Percent Annual Chance Flood"?

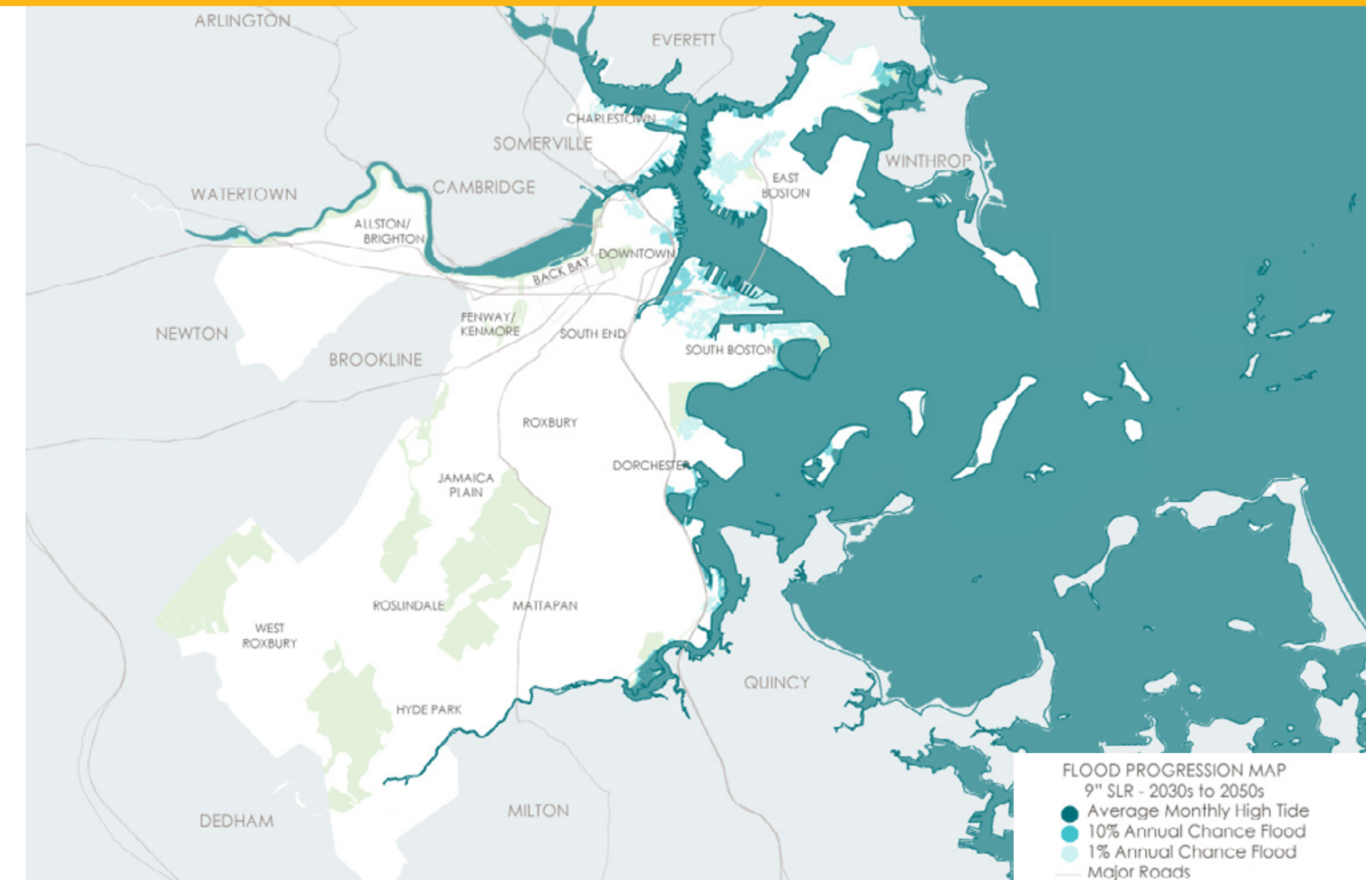
A "1 percent annual chance flood" is a flood event that has a 1 in 100 chance of occurring in any given year. Another name for this flood is the "100-year flood." Experts prefer not to use the "100-year" term since it gives the impression that a certain level of flooding will only occur once every 100 years. In fact, it has a one percent chance of occurring in any given year and can even occur multiple times in a single year or decade.

Over a 30-year period, there is almost a one in three chance that a 1 percent annual chance flood will occur at least once.

NEAR TERM (2030s–2050s)

FLOOD PROGRESSION

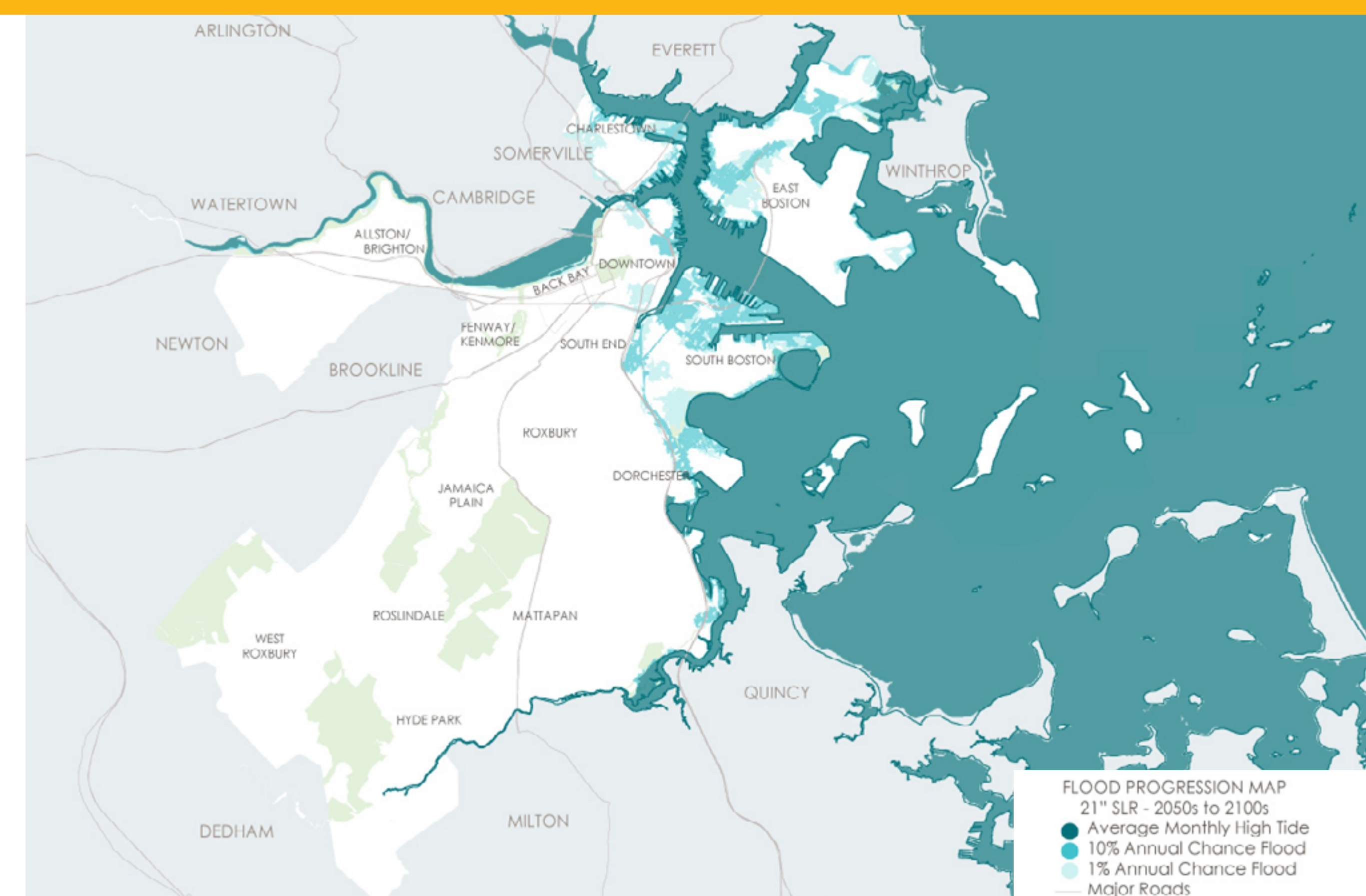
In the near term (2030s–2050s), coastal and riverine flood exposure will be concentrated in South Boston, East Boston, Charlestown, and Downtown and represents a significant threat to these neighborhoods and the rest of the city. Across the city, a severe flood with a 1 percent annual chance of occurring would inundate 2,100 buildings, representing $20 billion in real estate value, and including the homes of 16,000 Bostonians. Such an event would cause an estimated $2.3 billion in physical damages to buildings and property and other economic losses, including relocation and lost productivity. Considering the impact of flood events of multiple probabilities, 70 percent of economic losses are concentrated in Downtown and South Boston, with their high densities of businesses and valuable properties.

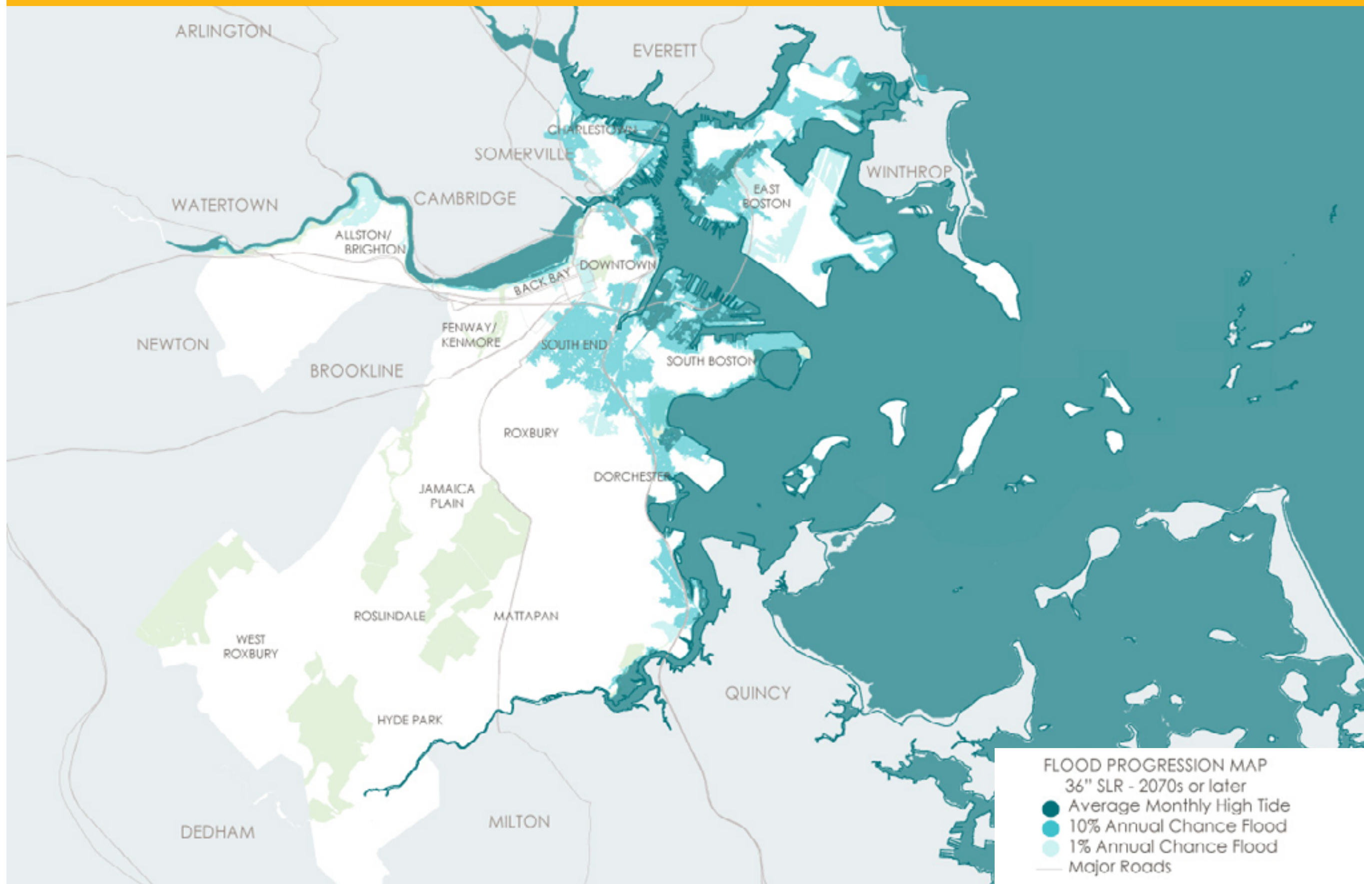


MID TERM (2050s–2100s)

FLOOD PROGRESSION

In the second half of the century (2050s–2100s), coastal and riverine flood exposure may increase across waterfront neighborhoods and start to be significant in Dorchester. As sea levels rise, the depths of flooding along the waterfront will increase, and floodwaters will start to threaten higher grounds and areas further inland that currently face little or no flood risk.





LATER TERM (2070s ONWARDS)
FLOOD PROGRESSION

In the late century (2070s or later), a significant portion of Boston's current land may be inundated every month. Exposure to severe coastal and riverine flooding will expand to vast areas of the city, including inland neighborhoods like the South End and neighborhoods along the Charles River. By penetrating past low-lying areas around Fort Point Channel and by the New Charles River Dam, floodwaters from storms can reach these areas that are not currently exposed to significant coastal and riverine flooding. Compared to the near term (2030s–2050s), over three times the amount of land—almost one-fifth of Boston's land area—will be exposed to inundation from a lower probability (1 percent annual chance) event. Five percent of Boston's total land area will be inundated at high tide at least once a month, even without any storm conditions.

Neighborhoods	Total Land Area (Acres)	LAND AREA EXPOSED (ACRES) 9" SLR 1% annual chance	21" SLR 1% annual chance	36" SLR 1% annual chance	36" SLR AMHT	PERCENT OF NEIGHBORHOOD EXPOSED 9" SLR 1% annual chance	21" SLR 1% annual chance	36" SLR 1% annual chance	36" SLR AMHT
I. Greatest Exposure & increasing throughout century									
Charlestown	870	120	310	460	110	14%	36%	54%	12%
Downtown	770	110	240	350	70	14%	31%	45%	10%
East Boston	3,340	540	1,040	1,680	480	16%	30%	49%	14%
Harbor Islands	820	200	230	260	200	25%	28%	32%	24%
South Boston	1,940	470	930	1,220	360	24%	48%	63%	19%
II. Lower Exposure today, but significant jump late century									
Allston / Brighton	2,940	30	70	240	20	1%	2%	7%	1%
Back Bay / Beacon Hill	460	<10	<10	80	<10	<1%	1%	17%	<1%
Roxbury	2,770	<10	<10	130	<10	<1%	<1%	5%	<1%
Dorchester	3,780	240	430	750	220	6%	11%	20%	6%
South End	640	<10	20	450	<10	<1%	3%	71%	<1%
III. Other Neighborhoods									
Fenway / Kenmore	620	<10	<10	<10	<10	<1%	<1%	<1%	<1%
Hyde Park	3,260	0	0	0	0	0	0	0	0
Jamaica Plain	2,260	0	0	0	0	0	0	0	0
Mattapan	1,560	0	0	0	0	0	0	0	0
Roslindale	2,250	0	0	0	0	0	0	0	0
West Roxbury	3,350	0	0	0	0	0	0	0	0
Boston Total	**31,720**	**1,720**	**3,280**	**5,630**	**1,470**	**8%**	**10%**	**18%**	**8%**

AMHT is the Average monthly highest tide

Climate Ready Boston selected sea level rise scenarios (9 inch, 21 inch, and 36 inch) that are likely to occur within the century to focus the discussion on how Boston will adapt to climate change. The actual sea level rise Boston experiences will be driven by many factors, including global carbon emissions. Climate models show that sea level rise in the near and intermediate term is largely locked in due to emissions that have already been released into the atmosphere. In the first half of the century (2030s–2050s), nine inches of sea level rise are expected even if there is a major reduction in emissions. Twenty-one inches or more of sea level rise are expected in the second half of the century (2050s–2100) regardless of the level of emissions.

The highest sea level rise considered in this report, 36 inches, is highly probable toward the end of the century if emissions remain at the current level or even if there is a moderate reduction in emissions.

If there is a major emissions reduction, the chance of 36 inches or more of sea level rise by the end of the century is still just slightly less than 50 percent. If emissions remain at current levels, there is an approximately 15 percent chance that sea levels will rise at least 7.4 feet by the end of century, a scenario far more dire than those considered here. Any adaptation to even the lower end of projections for sea level rise will require significant long-term effort, and the city must therefore start adapting now.

India Wharf view from the Harbor Walk — High Tide during October
Image courtesy of Sasaki

As the sea level continues to rise, the likelihood of major floods will increase from a 1% annual chance to a **monthly reality.**

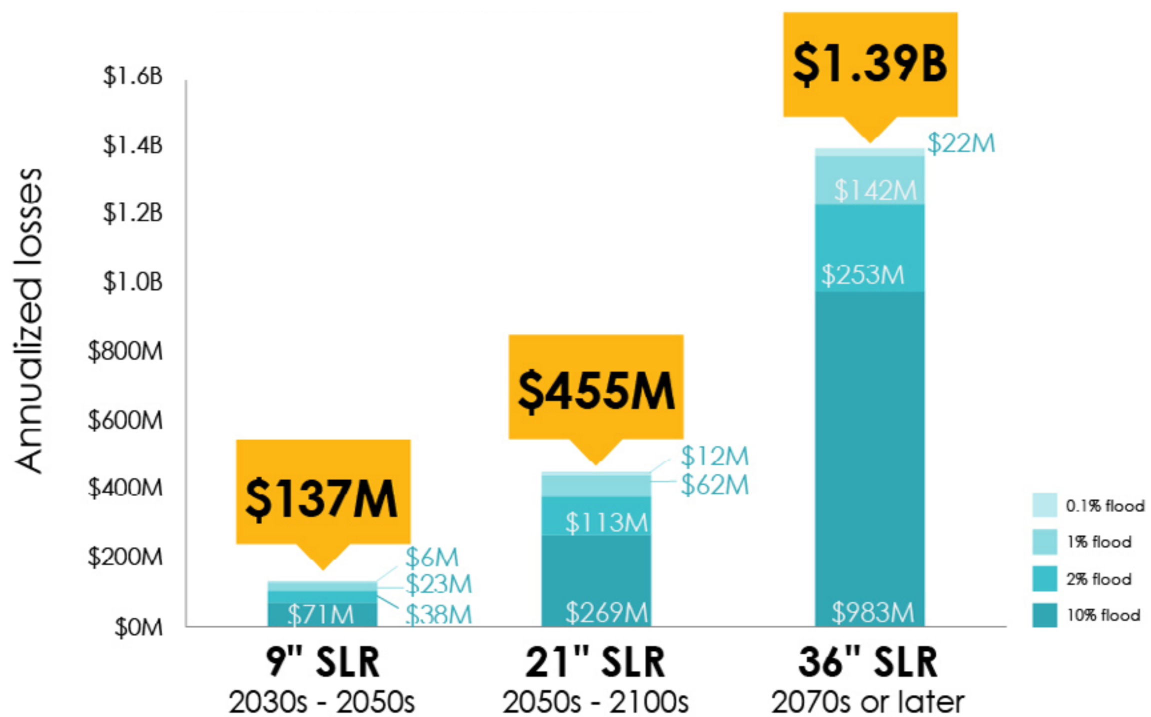
A **1% annual chance** flood **2030s - 2050s** ≈ A **10% annual chance** flood **2050s - 2100s** ≈ Monthly flooding **2070s or later**

As sea levels continue to rise, severely damaging floods will shift from a rare occurrence to a monthly reality. In the near term, a flood event inundating 5 percent of the city will have a 1 percent chance of occurring in any given year. By mid-century, such a flood will become ten times more likely, and by the late century, that magnitude of flooding will occur at least once a month. This means that between 10 and 20 percent of Charlestown, East Boston, Downtown, and South Boston will face high-tide flooding, even when there is no storm.

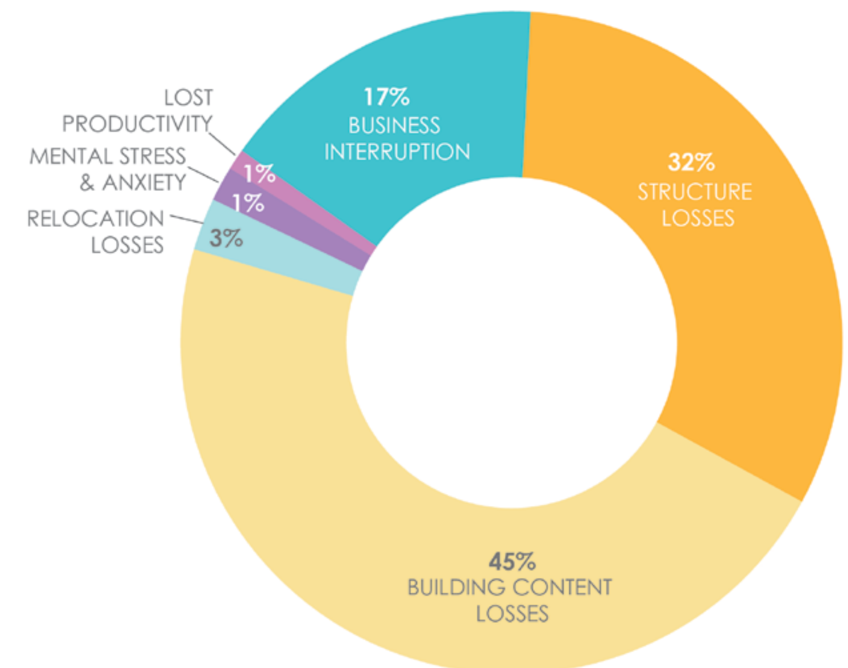
As climate change progresses over the course of this century, ever greater areas of Boston will be exposed to more frequent and more severe flooding.

- In the late century (2070s or later), 75 percent of buildings that will be exposed are either residential or mixed-use, exposing over 88,000 people (nearly 15 percent of Boston's population) to coastal and riverine flooding.
- More than 10 percent of Boston's existing buildings will be exposed to late-century coastal and riverine flooding.
- Toward the end of the century, 5 percent of Boston's real estate market value can be expected to suffer flood exposure to high tides, increasing to 25 percent for less frequent but more severe events.

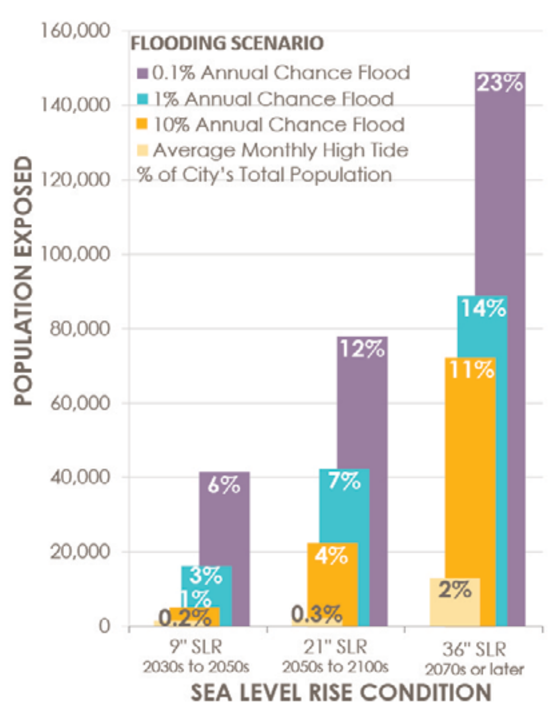
Annualized losses will increase with sea level rise...



CITY OF BOSTON ANNUALIZED LOSSES
36 INCH SEA LEVEL RISE CONDITION



CITYWIDE POPULATION EXPOSED



Severely damaging flood events will become more common over time. As flood risk increases this century and beyond, not only do the total expected annualized losses increase dramatically, but the share of these losses attributable to high-probability floods (10 percent chance of occurring in any given year) also becomes much greater.

Coastal and riverine flooding can impact the local and regional economy through physical damages, stress factors (mental stress and anxiety and lost productivity), displacement costs, and losses due to business interruption. Loss estimations presented in this assessment are reported as an annualized value for each sea level rise condition; annualized values represent the total of the product of single losses expected for each projected sea level rise condition and the chance of occurring in any given year.

Coastal and riverine flooding can disrupt the Critical infrastructural systems—including transportation, energy, communication, and essential facilities—on which Bostonians rely. Over time, an increasing number of these systems will be exposed to flooding.

- Key components of Boston's transportation system, most notably MBTA T service and major roads, may be at risk to coastal and riverine flood impacts in the near future.
- There are 240 essential and public facilities in the area exposed to late-century coastal and riverine flooding for lower probability storms.

Although the Vulnerability Assessment chapter of this report contains a discussion of the vulnerabilities of multiple infrastructural systems, further study is necessary, especially for energy and telecommunications systems.

The evacuation routes vulnerable to flooding include:

- I-93
- McClellan Highway Callahan Tunnel
- I-90 Ted Williams Tunnel
- Morrisey Boulevard
- Storrow Drive
- Tremont Street

Increasing Boston's Climate Readiness

Guided by the Vulnerability Assessment findings, which identified and quantified the impacts of future climate change, the City should undertake a set of climate resilience initiatives to address Boston's climate risks.

These initiatives will increase Boston's ability to thrive in the face of intensifying climate hazards, leading to improved quality of life for all residents, especially the most vulnerable, and creating stronger neighborhoods and a healthier environment.

The climate resilience initiatives build on a broad set of efforts undertaken to date by the City and its partners to prepare Boston for climate change.

To develop the initiatives, Climate Ready Boston reviewed past climate adaptation plans, conducted interviews and focus groups with a broad range of local stakeholders, and examined best practices from other cities across the world that are contending with climate change impacts.

CLIMATE RESILIENCE PRINCIPLES

The City drew on five principles for successful resilience to climate change based on lessons from other cities. These principles include the following:

1. **Generate multiple benefits.** Effective climate resilience initiatives both reduce risks from climate hazards and create other benefits. Resilience initiatives that produce multiple benefits generate more resources to support their implementation and sustainability. Flood barriers that also provide recreational open space, developable land, or upgraded roadways represent examples of multiple-benefit solutions. Nonphysical interventions also can offer multiple benefits, as evidenced by programs that help businesses and households make operational changes to reduce their flood risk while also lowering utility costs or reducing insurance premiums. Multiple-benefit approaches enable Boston to address some of the other pressing challenges that it faces beyond just climate risks.

2. **Incorporate local involvement in design and decision making.** Effective resilience initiatives require on-the-ground knowledge and sustained community support for implementation and long-term operations and maintenance. Local stakeholders can help illuminate critical resilience opportunities in their communities and generate creative ideas for solving multiple challenges at once.

3. **Create layers of protection by working at multiple scales.** Layers that are independently effective can also work together to provide mutual support and reduce the risk of a catastrophic failure associated with a single line of defense. For example, to address extreme heat, adding green infrastructure (e.g., increasing tree canopy) in combination with building-scale adaptations (e.g., using cool roofing and paving materials or increasing energy efficiency) is more effective than doing either independently. Shading from the tree canopy reduces the cooling load on the building, and the retrofitted building radiates less heat, with a failure to either layer having less impact because of the other.

4. **Design in flexibility and adaptability.** Climate conditions will continue to change over time, and resilience initiatives must be designed to adapt to them. For example, the 24-hour rainfall for a ten-year storm is projected to increase through the century. To be effective, the stormwater system must be flexible enough to adapt to this increase in extreme precipitation. In practice, this often means decentralized, distributed stormwater storage across cities that can be expanded without disrupting the gray stormwater system. Similarly, the elevation of 1 percent annual chance floods is also projected to increase throughout the century. Buildings can be built today with high ground-floor ceilings so that the ground floor can be filled in as sea levels rise over time.

5. **Leverage building cycles.** Buildings and infrastructure experience a natural cycle of rehabilitation and replacement over time. Taking adaptation actions within the context of the natural building cycle can reduce disruption and cost, as in the case of adding green infrastructure to roads as they are being rebuilt, rather than pulling them up just to install green infrastructure. While the natural building cycle progresses, operational changes, as opposed to physical adaptations, can be made to reduce risks. For example, retailers can move the inventory stored in the basement of their stores onto shelves to reduce flood damage in the near term, before local flood defenses are built. The development of new housing and job centers along the waterfront or in other flood-exposed areas presents opportunities to not only construct individual buildings prepared for flood risk but to also raise funds for the construction of area-wide flood defenses.

Addressing the Specific Characteristics of Each Climate Hazard

The resilience initiatives are designed to respond to the geographic scale, frequency, intensity, and projected growth of each climate hazard. For **extreme heat**, this calls for resilience initiatives that can be applied throughout the city, prioritize vulnerable populations, and address gaps in the capacity of buildings to cool themselves. The resilience initiatives addressing **stormwater flooding** are intended to be applied in affected pockets in each neighborhood and emphasize the ability to keep up with increased precipitation over time. **Coastal and riverine flooding** calls for a very different approach. The resilience initiatives are intended to be targeted to the areas directly exposed and involve the creation of significant new infrastructure systems in addition to the adaptation of existing systems and buildings.

LAYERS, STRATEGIES, AND INITIATIVES

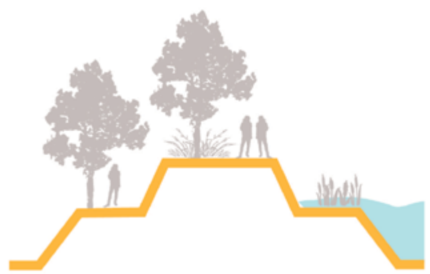
The climate resilience initiatives have been organized into four layers and eleven strategies. The layers represent an approach to building resilience at different scales: the community, the shoreline, infrastructure assets, and buildings. The layers are designed to support and reinforce each other.

UPDATED CLIMATE PROJECTIONS

Ensure that decision making in Boston is informed by the latest Boston-specific climate projections.

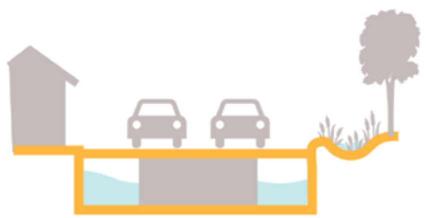
PREPARED AND CONNECTED COMMUNITIES

Support educated, connected communities in pursuing operational preparedness, adaptation planning, and emergency response.



PROTECTED SHORES

Reduce Boston's risk of coastal and riverine flooding through both nature-based and hard-engineered flood defenses.



RESILIENT INFRASTRUCTURE

Prepare the infrastructure systems that support life in Boston for future climate conditions and create new resilient systems.

ADAPTED BUILDINGS

Create a regulatory environment and financial and other tools to promote new and existing buildings that are climate ready.

Strategy 1.

Maintain up-to-date projections of future climate conditions to inform adaptation.

WHY Knowledge is the foundation for action. As global energy use and greenhouse gas emissions become clearer and as more data on the response of the Earth becomes available, climate projections will change. Bostonians need to remain informed to plan for the future.

WHAT The City should establish a Greater Boston Panel on Climate to update climate projections every five years. These projections should inform plans, policies, and regulations and be translated into readily accessible reports and maps.

Strategy 2.

Expand education and engagement of Bostonians on climate hazards and action.

WHY Climate adaptation cannot occur without an informed, engaged, and active public. Community members can provide deeper insight into how climate change is affecting their neighborhoods and businesses and create innovative and sensitive responses.

WHAT The City should work with partners from all sectors to inform and engage the Boston community on the risks from climate change and actions to reduce those risks. Different campaigns—targeting the general public, building owners, community facilities, businesses, and vulnerable populations who are more susceptible to the impacts of climate change—should promote short-term actions to reduce current risks while building support for larger-scale and longer-term measures.

Strategy 3.

Leverage climate adaptation as a tool for economic development.

WHY Over the coming decades, climate adaptation will require significant investments in the city's infrastructure, buildings, and other areas. The community can leverage this activity to promote equitable economic development, leaving Bostonians better prepared to thrive and face climate and other challenges.

WHAT The City should help train workers for jobs that will arise from climate adaptation projects and ensure that these projects follow the City's guidelines for local hiring, living wages, and employment of minority- and women-owned businesses

Strategy 4.

Develop local climate resilience plans to coordinate adaptation efforts.

WHY Some effects of climate change, such as increased temperatures, are spread across the city. Other, particularly coastal and riverine flooding, are more localized. Everywhere, these risks will interact with each other and with the social and economic needs of the neighborhood in particular ways. Coordinated adaptation actions can advance multiple community priorities simultaneously and use resources more effectively.

WHAT The City should develop local plans to address climate adaptation along with other community priorities. Through in-depth community engagement, the plans should include district-scale flood protection, infrastructure adaptation, and land-use planning, all in coordination with Imagine Boston 2030, 100 Resilient Cities, GoBoston 2030, and other planning efforts.

Strategy 5.

Create a coastal protection system to address flood risk.

WHY Coastal and riverine flooding poses a major and increasing threat to communities along Boston's waterfront and to the vitality of the city itself.

WHAT The City and its regional partners should investigate major "gray" and "green" infrastructure investments to address flood risk. The City should ensure that development in flood-prone areas does not prevent the future implementation of flood protection. The flood protection system should incorporate building-scale, district-scale, and harbor-wide measures.

Strategy 6.

Coordinate investments to adapt infrastructure to future climate conditions.

WHY Boston's infrastructure for power, water, transportation, communication, and more is a complex network with many public and private owners, operators, and regulatory authorities. As climate change presents new risks of failure, all stakeholders need to better understand the totality of vulnerabilities and to coordinate action to address them.

WHAT The City should establish an Infrastructure Coordination Committee with the region's major infrastructure organizations. The committee would develop planning and design standards aligned with up-to-date climate projections, identify cascading vulnerabilities, establish coordination mechanisms, and align adaptation efforts with other planning priorities.

Strategy 7.

Develop district-level energy solutions to increase decentralization and redundancy.

WHY Decentralized infrastructure of many kinds has the potential to combine climate adaptation with greenhouse gas reduction and economic development. Local sources that can keep operating during wider power failures could maintain the community's capacity to keep safe and cool as the frequency and intensity of heat waves rise.

WHAT The City should pursue community energy solutions, such as district energy systems or microgrids, that increase energy reliability and decrease greenhouse gas emissions. Priority sites should include areas with clusters of affordable housing or critical facilities.

Strategy 8.

Expand the use of green infrastructure and other natural systems to manage stormwater, mitigate heat, and provide additional benefits.

WHY Climate change will make it more difficult to manage stormwater and keep Bostonians cool, dry, and healthy. Green infrastructure, which relies on natural processes, can address these challenges and improve the safety and beauty of the public realm.

WHAT Building on past investments, the City should increase expand green infrastructure on public and private lands, in particular by developing sustainable funding sources and maintenance programs.

Strategy 9.

Update zoning and building regulations to support climate readiness.

WHY The current regulations that govern development in Boston do not have specific requirements for preparing for future climate conditions. In some cases, they may even pose obstacles to doing so.

WHAT Building on current requirements, the Boston Planning and Development Agency should propose land-use and other regulations that ensure that new development is ready for future climate conditions. The City should advocate for changes to the Massachusetts Building Code and explore measures that increase climate-ready retrofits in existing buildings.

Strategy 10.

Retrofit existing buildings against climate hazards.

WHY Most of the buildings in Boston that need to be prepared for climate change this century are already standing. The adaptation of existing buildings can be technically, operationally, and financially difficult. Property owners, particularly those with smaller or less valuable properties, may require technical or financial assistance.

WHAT The City should create programs to prepare existing buildings for climate change. Priorities should include buildings facing near-term flood risk and those with a public purpose or vulnerable populations. Programs could include resilience audits, investments in municipal facilities, support for backup power at facilities for vulnerable populations, and a toolkit of financing strategies.

Strategy 11.

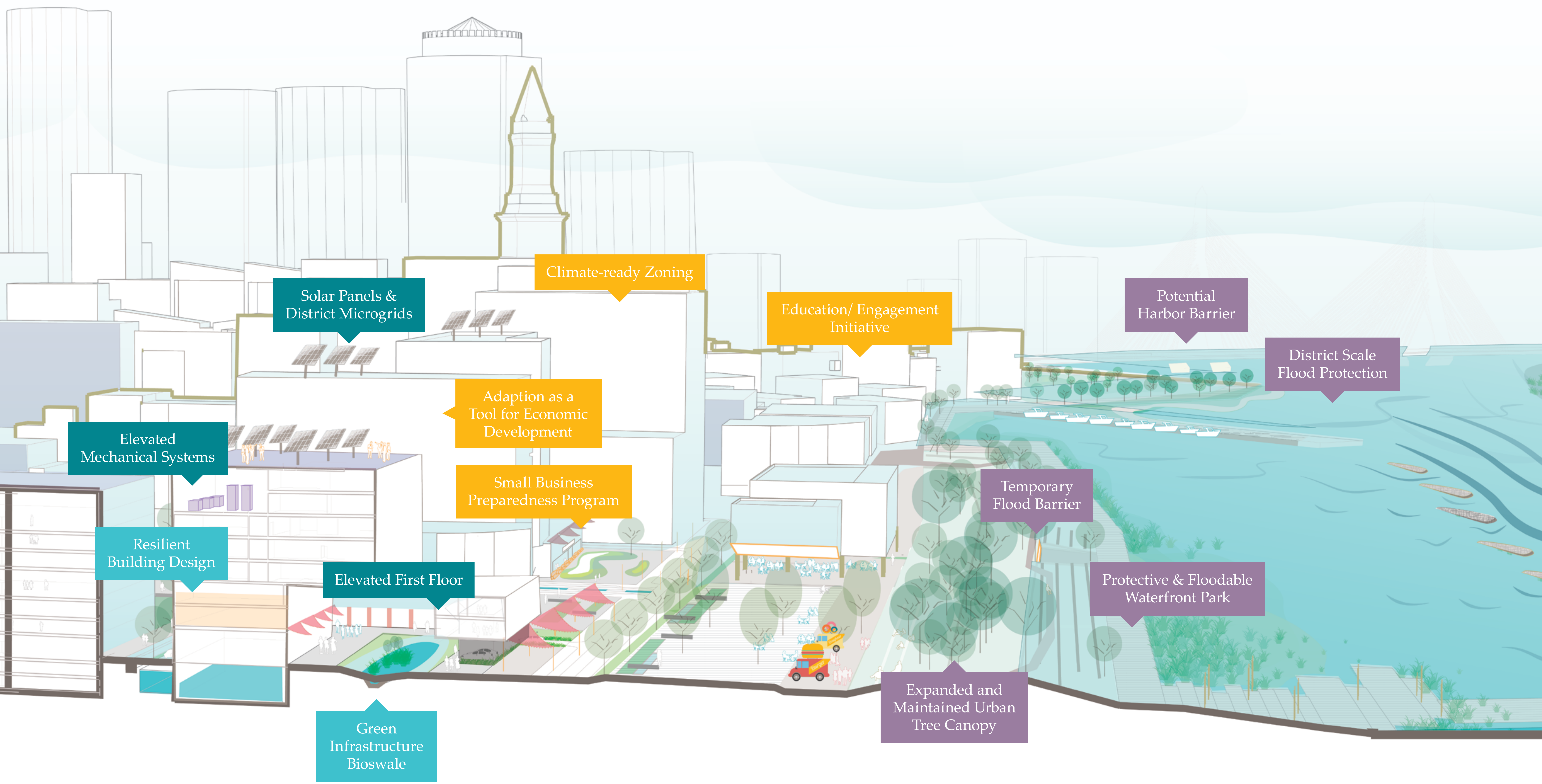
Insure buildings against flood damage.

WHY Whatever actions the community takes, natural disasters may still occur. Flood insurance is an indispensable tool for supporting recovery after a flood. Affordable access to appropriate levels of flood insurance coverage is critical to protecting property owners' investments and neighborhoods' stability.

WHAT The City should promote appropriate flood insurance for property owners. This should include joining the National Flood Insurance Community Rating System to obtain flood insurance discounts through advanced floodplain management and advocating for reforms to better align premiums with actual risk.

ADAPTING TO CLIMATE CHANGE

PROTECTED SHORES | PREPARED AND CONNECTED COMMUNITIES | RESILIENT INFRASTRUCTURE | ADAPTED BUILDINGS



Implementation

Climate Ready Boston's proposals are diverse in scope and scale. They are short term and long term, citywide and neighborhood specific, municipal and regional, regulatory and financial.

Some actions can be undertaken simultaneously; others must proceed in a certain order. They cannot all be done at once, because they would overwhelm government and community capacity. Furthermore, they do not need to be done all at once. Because climate change will accumulate over time, Boston's response, if thought through carefully, can proceed over time too.

The Recommended Roadmap presents a timeline and designated lead agency for undertaking these initiatives. The timeline has three divisions—within two years, within five years, and long-term—plus an arrow indicating if an initiative is ongoing. Over half of the initiatives will be ongoing because, once started, they will need to continue or repeat indefinitely; for example, climate projections should be updated with new data that becomes available over time.

The time divisions represent a rough prioritization based on many factors, including the following:

- Who and what are most at risk now?
- Are there existing efforts—climate related or related to other initiatives—upon which the next phase of climate initiatives can build?
- Are resources—human, technical, fiscal—available to undertake this work?
- Is one initiative a necessary or desirable foundation for another?
- What is the risk or cost of delay, and who bears that risk or cost?
- Who has to take action?
- Is there already community or sectoral support?
- How difficult is implementation?

One question underlying almost all of the initiatives is how to pay for them. Some initiatives explicitly address the financial question, but even those that do not address this question will be affected by it.

Some of the key initiatives that need to be started in the next two years include the following:

- Initiative 2-1. Expand citywide climate readiness education and engagement campaign
- Initiative 4-1. Develop local climate resilience plans to support district-scale climate adaptation (for the first selected districts)
- Initiative 5-2. Determine a consistent evaluation framework for flood defense prioritization
- Initiative 6-1. Establish an Infrastructure Coordination Committee
- Initiative 8-2. Develop a sustainable operating model for green infrastructure on public land and right-of-way
- Initiative 9-2. Revise zoning code to support climate-ready buildings
- Initiative 10-2. Prepare municipal buildings for climate change

Image courtesy of Southie Trees

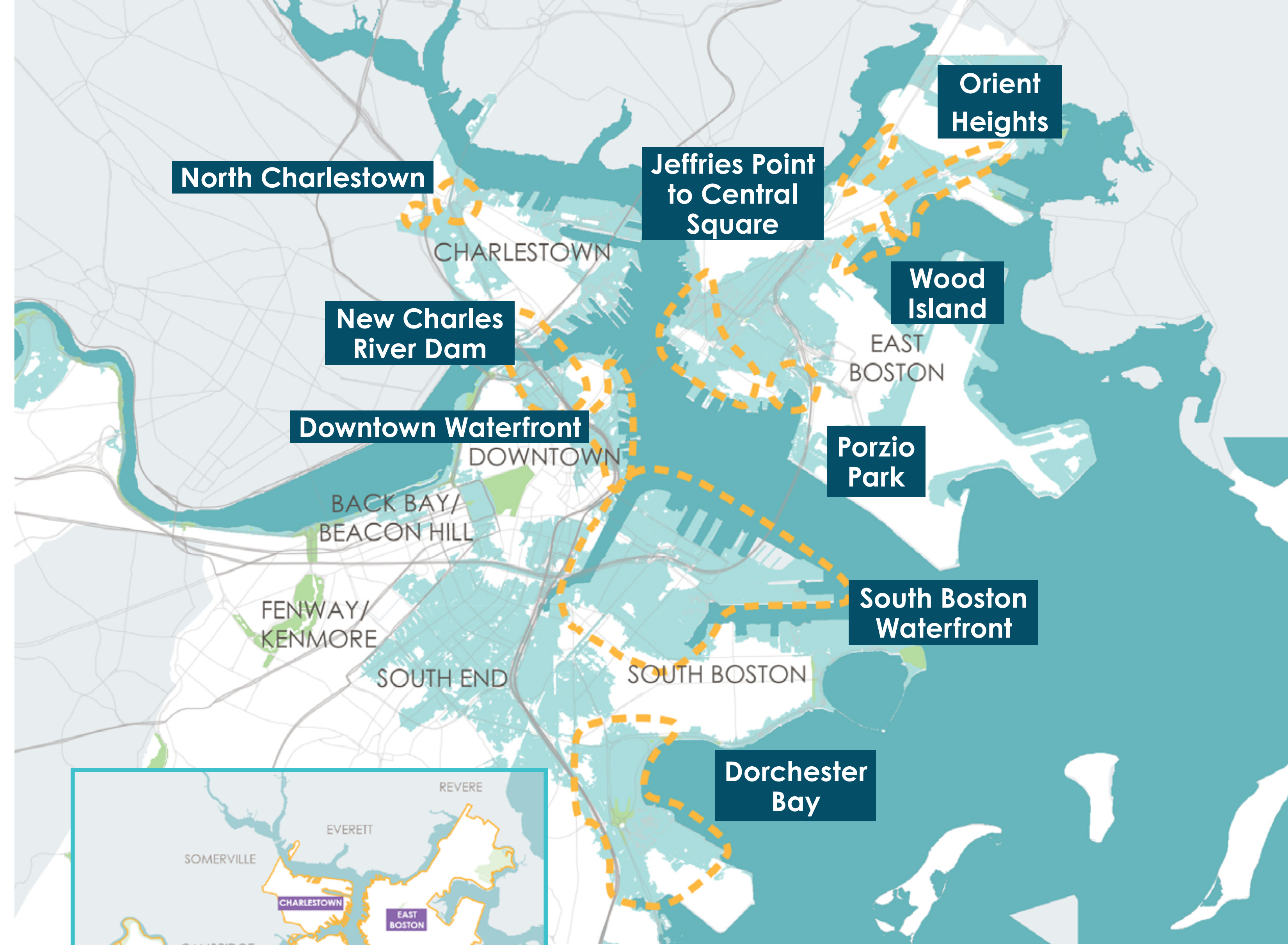
Focusing on Neighborhoods

To guide adaptation planning across Boston's neighborhoods, especially when climate vulnerabilities are spatially concentrated, Climate Ready Boston examined several areas in more detail:

- **Focus Area Vulnerability Assessments** provide deeper insight into the types of vulnerabilities that the people, buildings, infrastructure, and economy face in specific areas.
- **Focus Area Resilience Initiatives** show how the citywide resilience initiatives can be applied to specific areas within Boston.
    - Charlestown
    - Charles River
    - Dorchester
    - Downtown
    - East Boston
    - Roxbury
    - South Boston
    - South End

Seven out of the eight focus areas contain coastal neighborhoods that face significant risks from coastal and riverine flooding. Where multiple neighborhoods are exposed to flooding from the same source in the same time period, they are grouped together as a single focus area (e.g., all of the Charles River neighborhoods face flood exposure when the Charles River Dam is flanked or overtopped).

The eighth focus area, Roxbury, was developed to serve as an illustrative example of multiple vulnerabilities, based on the intersection of all three climate hazards—coastal and riverine flooding, stormwater flooding, and extreme heat—and demonstrate the application of resilience initiatives focused on these risks.



36 INCHES SLR (2070S OR LATER)
DISTRICT-SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD

Based on the citywide vulnerability assessment and the focus-area analyses, Climate Ready Boston proposes nine locations for flood-protection interventions. As sea level rises over the century, the number of interventions needed increases, and their cumulative effectiveness becomes more important.

CLIMATE READY BOSTON FOCUS AREAS
HEAT & STORMWATER AND COASTAL FLOODING
COASTAL HAZARD
FOCUS AREAS

Image courtesy of Sasaki

These bold and creative actions will support the city's vitality and livability.

CLIMATE READY BOSTON
RECOMMENDED ROADMAP

INITIATIVE WITH DEADLINE —| CONTINUOUS INITIATIVE →

Climate Projection Consensus

STRATEGY 1

Maintain up-to-date projections of future climate conditions to inform adaptation.

#	Initiative	Within 2 years	Within 5 years	Long-term
1.1	Launch the Greater Boston Panel on Climate Change and require periodic updating of Boston-specific climate projections.		Greater Boston Panel on Climate is launched.	Climate projections updated every 5 yrs. (continuous)
1.2	Create updated local flood maps to support planning, policy, and regulation.	City establishes policy on planning flood standards.	Future flood maps are incorporated into City policy and regulation.	Flood maps are periodically updated. (continuous)

Prepared and Connected Communities

STRATEGY 2

Expand education and engagement of Bostonians about climate hazards.

#	Initiative	Within 2 years	Within 5 years	Long-term
2.1	Expand Citywide Climate Readiness Education and Engagement campaign.	Citywide campaign is launched.		(continuous)
2.2	Launch a Climate Ready Buildings Education Program for property owners and users.	Climate Ready Buildings Education Program is launched.		(continuous)
2.3	Conduct an outreach campaign to facilities that serve vulnerable populations to support preparedness and adaptation.		Outreach campaign is launched.	(continuous)
2.4	Update the City's heat emergency action plan.	Heat emergency action plan is updated.	(deadline)	
2.5	Expand Boston's Small Business Preparedness Program.	Small business preparedness resources developed.	Climate adaptation is incorporated into Main Streets program. (deadline)	

Prepared and Connected Communities

STRATEGY 3

Leverage climate adaptation as a tool for economic development.

#	Initiative	Within 2 years	Within 5 years	Long-term
3.1	Identify resilience focused workforce development pathways.		Pathways are developed and incorporated into existing workforce programs. (deadline)	
3.2	Pursue inclusive hiring and living wages for resilience projects.	(continuous)		
3.3	Prioritize use of minority-and women-owned businesses for resilience projects.	(continuous)		

Protected Shores

STRATEGY 4

Develop local climate resilience plans to coordinate adaptation efforts.

#	Initiative	Within 2 years	Within 5 years	Long-term
4.1	Develop local climate resilience plans in vulnerable areas to support district-scale climate adaptation.	Initial plans are launched.	Complete initial plans.	Plans are completed for all focus areas and periodically revised. (deadline)
4.2	Establish local climate resilience committees to serve as long-term community partners for climate adaptation.	First committee is established.		Committees are established for all focus areas. (deadline)

Protected Shores

STRATEGY 5

Create a coastal protection system to address flood risk.

#	INITIATIVE	IMPLEMENTATION PERIOD: WITHIN 2 YEARS	WITHIN 5 YEARS	LONG-TERM
5.1	**Establish Flood Protection Overlay Districts (FPOD) and require potential integration with flood protection.**	Policies for FPOD are studied.	Policies for FPOD are enacted.	
5.2	**Determine a consistent evaluation framework for flood defense prioritization.**	Evaluation framework is studied.	Evaluation framework is established.	
5.3	**Prioritize and study the feasibility of district-scale flood protection.**	Evaluation of district-scale flood defenses is initiated.	Evaluation is completed for highest-priority sites.	Evaluation of additional sites and continued implementation.
5.4	**Launch a harbor-wide flood protection system feasibility study.**	Evaluation of harbor-wide flood protection is initiated.		Decision on harbor-wide strategy is reached and, as needed, implementation launched.

Resilient Infrastructure

STRATEGY 6

Coordinate investments to adapt infrastructure to future climate conditions.

#	INITIATIVE	WITHIN 2 YEARS	WITHIN 5 YEARS	LONG-TERM
6.1	**Establish an Infrastructure Coordination Committee (ICC).**	ICC is launched.		
6.2	**Continue to collect important asset and hazard data for planning purposes.**	Data-sharing protocol is established.		
6.3	**Provide guidance on priority evacuation and service road infrastructure to the ICC.**	Priority evacuation and service roads are identified.		

Resilient Infrastructure

STRATEGY 7

Develop district-level energy solutions to increase decentralization and redundancy.

#	INITIATIVE	IMPLEMENTATION PERIOD: WITHIN 2 YEARS	WITHIN 5 YEARS	LONG-TERM
7.1	**Conduct feasibility studies for community energy solutions.**	Launch feasibility studies for community energy solutions at high-priority sites.	Implement community energy solutions at high-priority sites.	

Resilient Infrastructure

STRATEGY 8

Expand the use of green infrastructure and other natural systems to manage stormwater, mitigate heat, and provide additional benefits.

#	INITIATIVE	WITHIN 2 YEARS	WITHIN 5 YEARS	LONG-TERM
8.1	**Develop a green infrastructure location plan for public land and rights-of-way.**	Green infrastructure location plan is launched.		
8.2	**Develop a sustainable operating model for green infrastructure on public land and rights-of-way.**	New operating model is adopted by City.		
8.3	**Evaluate incentives and other tools to support green infrastructure.**	Evaluation of incentives is complete.		
8.4	**Develop design guidelines for green infrastructure on private property to support co-benefits.**		Design guidelines are set as regulation.	
8.5	**Develop an action plan to expand Boston's urban tree canopy.**	Canopy inventory is launched.	Canopy inventory is completed.	
8.6	**Prepare outdoor facilities for climate change.**		Adaptations are evaluated and prioritized across portfolio.	
8.7	**Conduct a comprehensive wetlands inventory and develop a wetlands protection action plan.**		Wetlands inventory is completed.	

Adapted Buildings

STRATEGY 9

Update building regulations to support climate readiness.

#	INITIATIVE	WITHIN 2 YEARS	WITHIN 5 YEARS	LONG-TERM
9.1	Establish a planning flood elevation to support zoning regulations in the future floodplain.	Analysis process initiated	Planning flood elevation is established for all development.	
9.2	Revise zoning code to support climate-ready buildings.	Review of zoning code launched.	Zoning changes are implemented.	
9.3	Promote climate readiness for projects in the development pipeline.	Notifications are sent to all permitted developments.		
9.4	Pursue state building code amendments to promote climate readiness.	Begin working with Commonwealth regarding building code amendments.		
9.5	Incorporate future climate conditions into area plans.	Standards are enacted as City policy for future plans.		

Adapted Buildings

STRATEGY 10

Retrofit existing buildings against climate hazards.

#	INITIATIVE	WITHIN 2 YEARS	WITHIN 5 YEARS	LONG-TERM
10.1	Establish a Resilience Audit Program for property owners.			Resilience audit program is launched.
10.2	Prepare municipal facilities for climate change.	Priority buildings are identified.	Priority retrofits are begun.	Retrofits continue.
10.3	Expand back-up power at private buildings that serve vulnerable populations.		First tranche of back-up power installation completed.	Back-up power installation continues.
10.4	Develop toolkit of building retrofit financing strategies.		Toolkit of financing strategies is released.	

Adapted Buildings

STRATEGY 11

Insure buildings against flood damage.

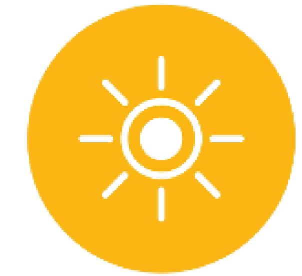
#	INITIATIVE	WITHIN 2 YEARS	WITHIN 5 YEARS	LONG-TERM
11.1	Evaluate the current flood insurance landscape in Boston.		Evaluation is completed.	
11.2	Join the NFIP Community Rating System.		City becomes active participant in CRS.	
11.3	Advocate for reform in the National Flood Insurance Program.		City begins advocacy for reforms that align with Boston's flood risks.	

Climate Projection Consensus

To better understand climate change impacts at the local level, the City of Boston and the Green Ribbon Commission convened the Boston Research Advisory Group (BRAG), a team of the region's top climate scientists, to develop the Climate Projection Consensus.

Image courtesy of Bud Ris

EXTREME TEMPERATURES



EXTREME PRECIPITATION

RELATIVE SEA LEVEL RISE

COASTAL STORMS

The Climate Projection Consensus summarizes how Boston's climate is expected to change throughout the twenty-first century, focusing on four climate factors: extreme temperature, relative sea level rise, extreme precipitation, and coastal storms. These factors drive Boston's major climate hazards: coastal and riverine flooding, stormwater flooding, and extreme heat (see Vulnerability Assessment for more details on these hazards and their impacts in Boston).

DEVELOPING A SCIENTIFIC CONSENSUS

This chapter is a summary of the BRAG Climate Projection Consensus report, describing future climate impacts in the Boston region, including extreme temperatures, sea level rise, heavy precipitation, and coastal storms. The full report is available at climateready.boston.gov/findings.

The BRAG was overseen by the University of Massachusetts Boston School for the Environment. BRAG members were organized into four working groups, each focused on a single climate factor: extreme temperature, relative sea level rise, extreme precipitation, or coastal storms. They collaborated across working groups on phenomena that cut across multiple climate factors, such as possible changes in snow frequency and amounts of coastal and riverine flooding. From October 2015 to January 2016, the working groups reviewed both academic and non-academic literature—including sources that varied in terms of their climate models, spatial resolution (scale), future time periods considered, and historical reference periods—and reported their findings of the scientific consensus. These reports were then compiled and edited by the University of Massachusetts Boston team and peer-reviewed by an international team of experts.

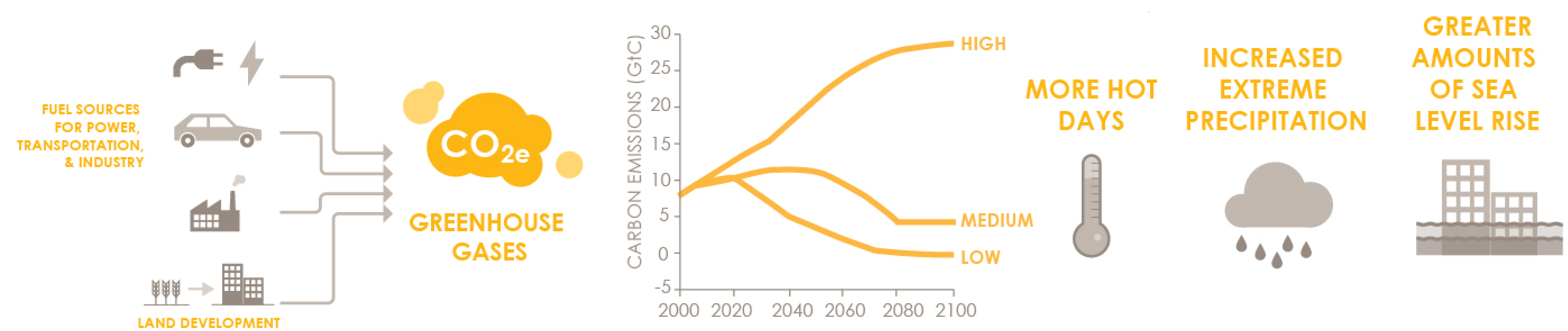
BOSTON'S "80 X 50" COMMITMENT TO EMISSIONS REDUCTION

Almost a decade ago, an Executive Order in Boston set a goal of reducing greenhouse gas emissions to 80 percent below 2005 levels by 2050 for municipal operations, and Boston has since expanded this goal to include citywide emissions. By 2013, there had been significant progress, with citywide emissions reduced by 17 percent[1], but there is still much work to be done. Boston's commitment is roughly in line with the global emissions reductions needed in order to keep the global temperature from rising more than two degrees Celsius relative to pre-industrial levels and with the low-emissions scenario analyzed in this report[2]. Boston's emissions are a very small fraction of global emissions; to avoid the worst potential impacts of climate change, the international community must enact strong emissions reduction policies.

[1] "2014 Climate Action Plan Update." Greenovate Boston, 2014.

[2] "Climate Change 2014: Mitigation of Climate Change." Intergovernmental Panel on Climate Change, 2014.

BOSTON'S FUTURE CLIMATE



For Boston to effectively plan for the impacts of climate change, there must be a shared understanding about what these impacts are likely to be. While the Intergovernmental Panel on Climate Change publishes global climate projections, the impacts of climate change vary by location, and therefore local projections are needed for better-informed planning. Since the late 2000s, there have been a number of vulnerability assessments and adaptation plans published for the Boston region, which have included local climate change projections. Because knowledge of climate change is continually growing, the BRAG was charged with identifying and evaluating the most-recent data available for the Boston region on climate change impacts.

The findings reported here reflect a consensus among the scientific community, including a scientific approach to uncertainty. Currently, the largest source of uncertainty related to understanding the future impacts of climate change is our lack of knowledge about the future amount of carbon that humans will emit into the atmosphere. To address this issue, scientists have defined a set of possible future carbon emissions scenarios to underlie their climate projections, based on projections about future population growth, development patterns, and energy use. Climate projections for the next few decades are relatively consistent, regardless of their underlying emissions scenario, because the past 200-plus years of human actions have already caused changes to our climate and will continue to do so. However, the projections become increasingly different further into the future, because human actions going forward will have an important and compounding effect on whether climate change accelerates or slows down. Another source of uncertainty is the complexity of natural processes, which scientists are still working to better understand. There is also a certain amount of naturally occurring interannual and interdecadal climate variability (also called "internal variability"). Finally, there appear to be "tipping points" in the climate system, which have the potential to result in larger, more rapid changes, and our understanding of these events is limited.

These climate projections use three emissions scenarios from the Intergovernmental Panel on Climate Change:

- A **high-emissions scenario,** often characterized as a continuation of business as usual;
- A **medium-emissions scenario,** in which emissions remain around their current levels through 2050 and then are slowly reduced in the second half of the century through moderate emissions reductions;
- A **low-emissions scenario,** in which net global emissions are reduced to less than a third of their current levels by 2050 and are brought to zero by about 2080 through major emissions reductions.

The magnitude of future changes depends on our actions today. Our choices about transportation, energy, and land use determine the level of greenhouse gases in the atmosphere. As greenhouse gas emissions increase, so do the impacts of climate change, like sea level rise, extreme precipitation, and extreme temperature. As we take actions now to address the change that is coming, it is critical that we continue to reduce our emissions and minimize future climate change.

EXTREME TEMPERATURES

KEY FINDINGS

Average temperatures in the Northeast have been slowly rising for over a century.

Temperatures in the northeastern United States increased by almost two degrees Fahrenheit between 1895 and 2011.

The rate of increase in average temperatures is accelerating. While over the past century, temperatures in the Northeast rose about two degrees, the increase over the next century may be greater than ten degrees.

As an urban area, Boston tends to be hotter than surrounding communities that are more suburban or rural. Urban areas generally tend to be hotter than nearby rural areas because concrete, steel, and other building materials retain more heat than vegetation. This phenomenon, known as the "urban heat island effect," is compounded by climate change.

Boston's summers are getting hotter. While the average summer temperature in Boston from 1981 to 2010 was 69 degrees, it may be as high as 76 degrees by 2050 and 84 degrees by 2100.

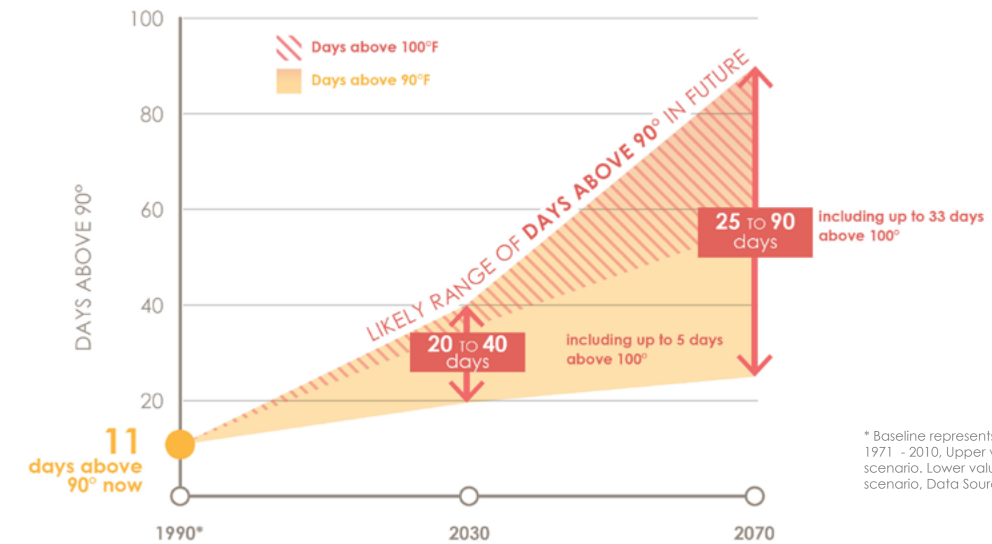
There will be more days of extreme heat. Compared to the period from 1971 to 2000, when an average of 11 days per year were over 90 degrees, there may be as many as 40 days over 90 degrees by 2030 and 90 days by 2070—nearly the entire summer.

Heat waves will become more common, last longer, and be hotter. The City of Boston defines heat waves as periods of three or more days above 90 degrees, and heat waves are a leading cause of weather-related mortality in the United States.

Although winters will likely be warmer, the risk of frost and freeze damage and cold snaps will continue. While from 1981 to 2010, Boston reached below freezing almost one out of three days per year, by the end of the century, this may happen only around one in ten days.

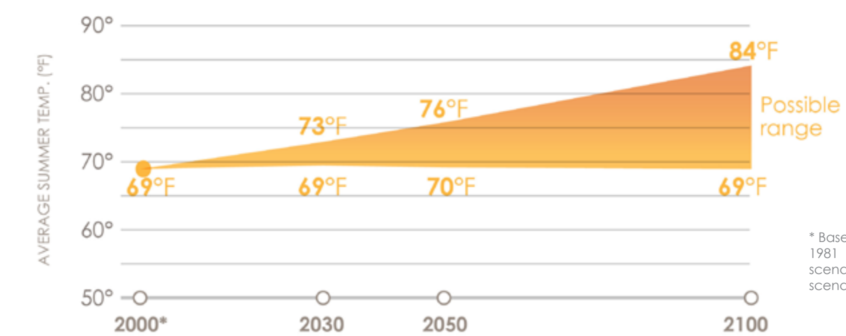
Future temperatures in Boston will depend on how much we are able to cut our greenhouse gas emissions. The rise in temperatures between now and 2030 is largely consistent among all emission scenarios. However, the scenarios show that cutting emissions now can greatly slow the rise in temperatures in the second half of the century.

THE NUMBER OF VERY HOT DAYS WILL INCREASE



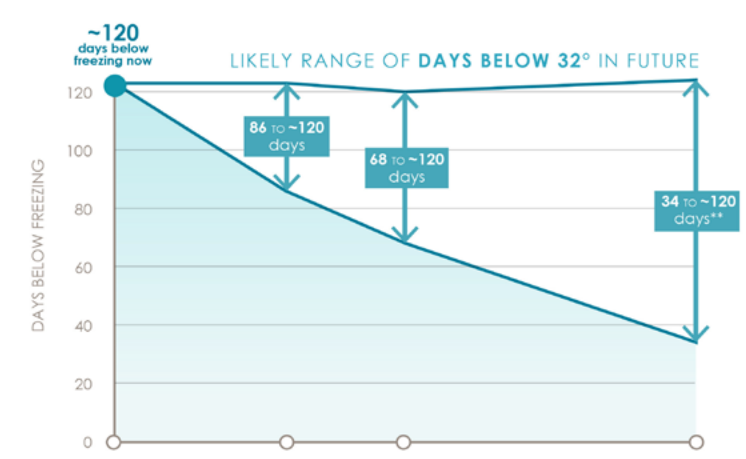
* Baseline represents historical average from 1971 - 2010, Upper values from high-emissions scenario. Lower values from low-emissions scenario, Data Source: Rossi et al. 2015

AVERAGE SUMMER TEMPERATURES WILL INCREASE



* Baseline represents historical average from 1981 - 2010, Upper values from high-emissions scenario. Lower values from low-emissions scenario, Data Source: Houser et al 2015

THE NUMBER OF VERY COLD DAYS MAY DECREASE



* Baseline represents historical average from 1981 - 2010, **Upper values from high-emissions scenario. Lower values from low-emissions scenario, Data Source: Houser et al. 2015

SEA LEVEL RISE

KEY FINDINGS

Sea level rise is caused by a combination of land ice melting, thermal expansion, and changes in land water storage.

Land ice melting includes the melting of mountain (alpine) glaciers, ice caps, and the continental-scale ice sheets on Greenland, West Antarctica, and East Antarctica. Thermal expansion describes the phenomenon that, as water warms, it generally occupies a greater volume. Land water storage describes activities that affect the amount of water stored on land, such as holding water in reservoirs or behind dams or pumping out underground water for irrigation and use by people.

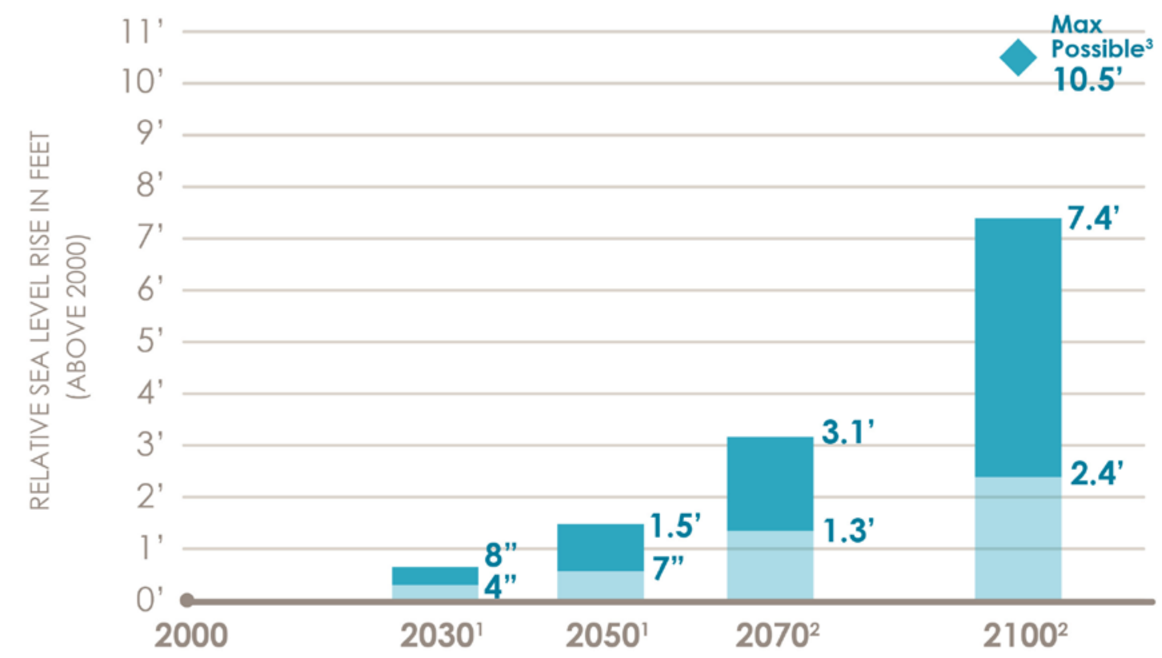
The relative sea level in Boston Harbor has risen over the past century. From 1921 to 2015, the overall trend in relative sea level rise was about 0.11 inches per year. Relative sea level is the difference in elevation between the sea surface and land surface at a specific place and time, so relative sea level rise can result from a combination of changes in the sea surface and changes in the land surface. In Boston, the sinking of the land surface—called "subsidence"—is relatively minor compared to changes in sea levels.

The pace of relative sea level rise is accelerating. Over the entire twentieth century, sea levels rose about nine inches relative to land. Another eight inches of relative sea level rise may happen by 2030, almost three times faster. By 2050, the sea level may be as much as 1.5 feet higher than it was in 2000, and as much as 3 feet higher in 2070.

As sea levels rise, a deeper harbor will mean higher and more powerful waves. Although Boston remains relatively protected from Atlantic waves by Winthrop, Hull, and the Harbor Islands, stronger waves are more likely to damage sea walls and erode beaches. The outer islands and peninsula shorelines of Boston Harbor are likely to experience these impacts to a greater extent than the Boston proper shoreline.

A major reduction in global greenhouse gas emissions can have a tremendous impact on the future of Boston Harbor. While sea level rise projections for 2030 are consistent across all emission scenarios, in later years big differences exist between scenarios. With a sharp emissions reduction, we may be able to keep end-of-century sea level rise to under two feet, while higher emissions may result in over seven feet of sea level rise.

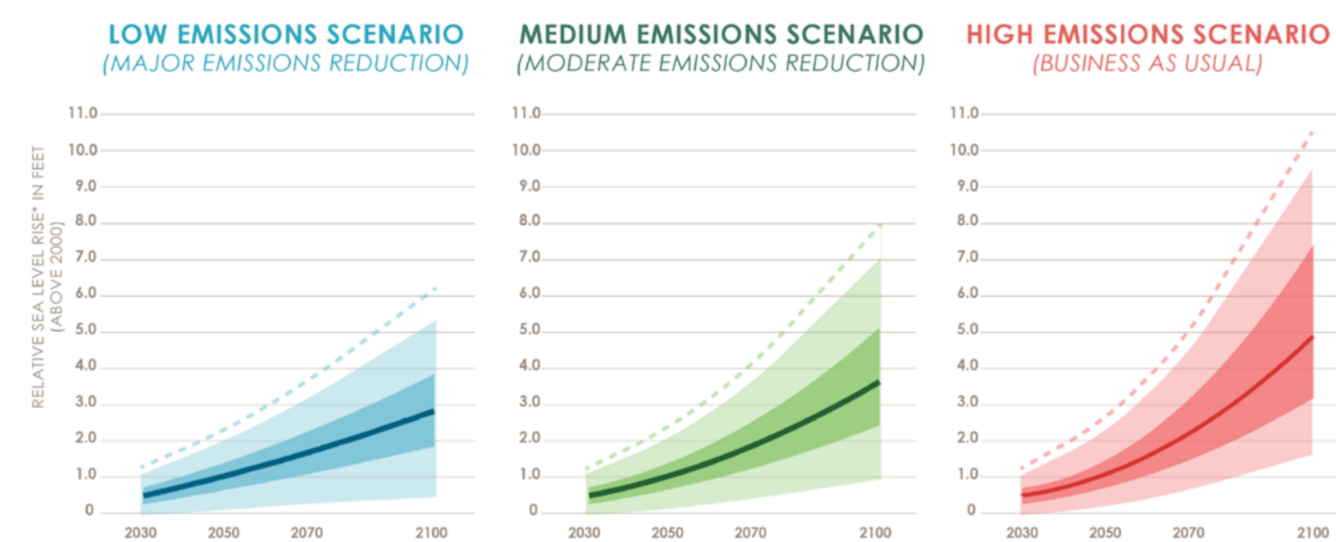
SEA LEVEL RISE IN BOSTON DURING THE TWENTY-FIRST CENTURY

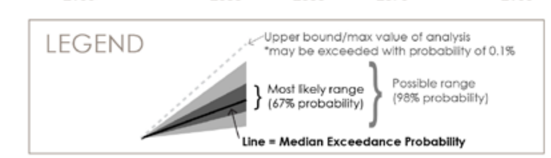


1 - Likely under all emission scenarios
2 - Likely under moderate to high emission scenarios
3 - Low probability under high emission scenario

Data Source: BRAG Report, 2016

THE AMOUNT OF SEA LEVEL RISE DEPENDS ON GREENHOUSE GAS EMISSIONS





* Relative sea level rise is the change in sea level resulting from a combination of increases in ocean height and decreases in land surface elevation ("subsidence").

Data Source: BRAG Report

EXTREME PRECIPITATION
KEY FINDINGS

In the Northeast, there has already been a very large increase in the intensity of extreme rain and snow.

From 1958 to 2010, there was a 70 percent increase in the amount of precipitation that fell on the days with the heaviest precipitation. This increase is greater in the Northeast than for any other region of the country.

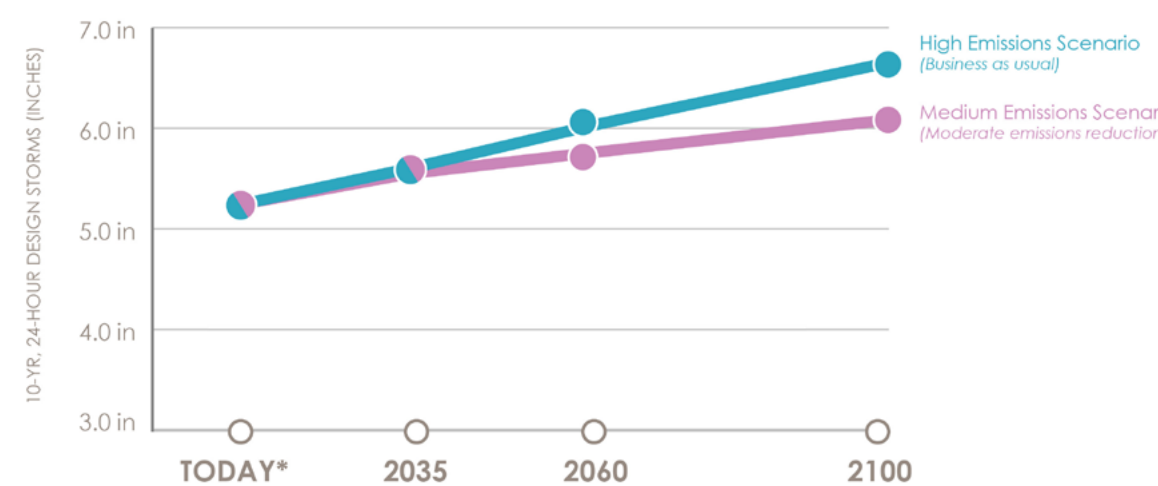
The increase in extreme precipitation is expected to continue. As the climate warms, more ocean water evaporates into the air, and warmer air can hold more water, supporting heavier precipitation events. Heavy precipitation events will continue to increase in Boston. However, due to the complexity of the processes underlying precipitation as well as natural variability, the magnitude of this increase is not yet clear.

While the total amount of annual snowfall will decrease, there may still be some heavy snow events through the end of the century. Based on regional projections, total snow accumulations could decrease 31 to 48 percent by 2100, and the start of the snow season is expected to be delayed. However, changes in daily heavy snowfall events can be quite different from changes in annual snowfall. Expected changes to individual heavy snow events, ice storms, and drought are not clear.

Both stormwater and riverine flooding are affected by extreme precipitation. Boston's stormwater drainage system may be overwhelmed by major rain events. It may be further compromised by sea level rise as drain outlets are flooded by the rising ocean, reducing the ability of the drainage system to convey stormwater to the coast. River flooding is also likely to increase, but there are large uncertainties associated with river flooding due to the complexity of the climate and hydrological systems involved.

If we take action to cut global greenhouse gas emissions, we can prevent the most extreme precipitation projections from becoming a reality. A commonly used measure of major rain and snow events is the amount of precipitation that has at most a one-in-ten annual chance of falling during a 24-hour period. While projections for these events are similar in the short term across different emission scenarios, by the end of the century, the difference between medium and high scenarios is about 10 percent.

RAINFALL FROM STORMS WILL INCREASE



* "Today" baseline represents historical average from 1948-2012
Confidence intervals are not available for these projections but are likely large, so these numbers should be considered as the middle of a large range

Data Source:
Boston Water & Sewer Commission

STORMS
KEY FINDINGS

For Boston, the storms that are of greatest concern are extratropical cyclones, followed by tropical cyclones.

Extratropical cyclones, which are more common and longer lasting in the Northeast than tropical cyclones, currently produce most of the storm-induced flooding in the Boston region and will continue to do so in the near future. These are storms that originate outside of the tropics and are sometimes called nor'easters. They can form during any time of the year but are most prevalent in the extended cold-season months. Tropical cyclones are storms that originate in the tropics and are called hurricanes once they reach a sustained wind speed of more than 74 miles per hour.

Current climate projections do not provide a clear projection of how the intensity, frequency, and trajectory (tracks) of tropical and extratropical storms will change. Extratropical storms (like blizzards and nor'easters) have cold air at their centers. Tropical storms, on the other hand, have warm air, which means that they can develop into hurricanes more quickly. There are large uncertainties about how climate change will affect future storms. This is particularly true for extratropical storms. For tropical storms, there is some evidence that their intensity has been increasing. If tropical storm intensity increases, major hurricanes (Category 3 and greater) could occur more frequently, even if the total number of tropical storms does not increase.

Rising sea levels mean that any given storm will cause more flooding in the future than it would today. During a storm, winds can blow ocean water toward the land, creating a "storm surge" on top of the baseline sea level. When storm surge is combined with tidal processes, the result is known as a "storm tide." With higher seas, less precipitation and a less powerful storm surge can produce the same amount of flooding as a more powerful storm would produce when the seas are lower.

Image courtesy of Sasaki

Climate Vulnerability Assessment

As the climate continues to change, three major climate hazards will increasingly impact Boston: extreme heat, stormwater flooding, and coastal and riverine flooding.

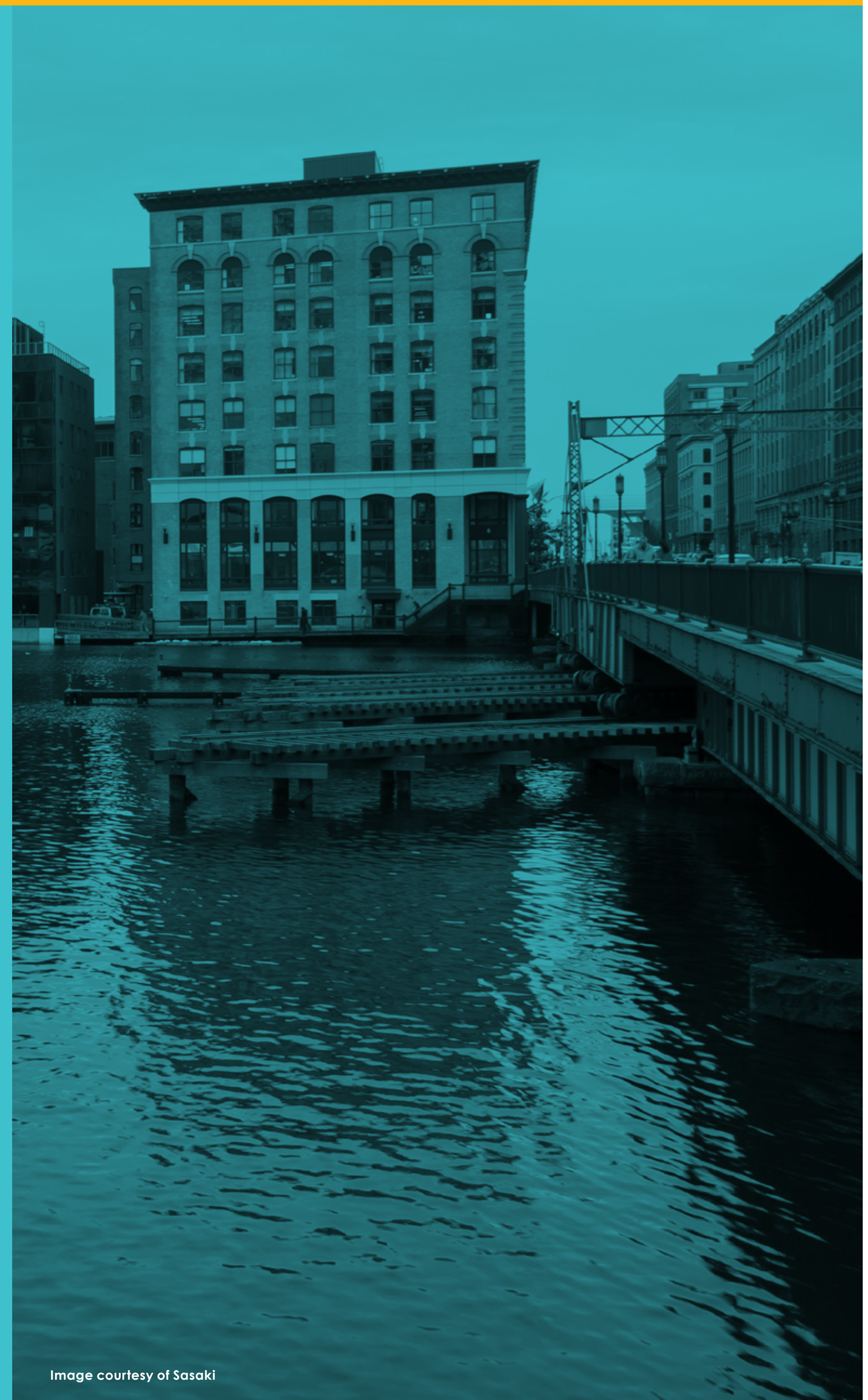


Image courtesy of Sasaki

Each of these hazards impacts the city's people, buildings, infrastructure, environment, and economy in different ways.

Stormwater flooding and extreme heat are evaluated as frequent or chronic hazards[1] that gradually degrade personal and economic well-being and directly expose parts of every neighborhood in Boston. **Coastal and riverine flooding is expected to be an acute hazard for much of the remainder of the century,** experienced through major storm events with immediate and long-lasting impacts. Moreover, **as sea levels continue to rise, coastal flooding from high tides is expected to become a chronic hazard, potentially flooding many low-lying neighborhoods along the waterfront on a monthly basis.** This is in addition to acute storm events, which are expected to become more severe and cause greater damage over time. This chapter, the Climate Ready Boston Vulnerability Assessment, analyzes how people, buildings, infrastructure, and the economy are affected by climate hazards. Vulnerability Assessment findings are reported at two scales: first, at the city scale (referred to herein as the Citywide Exposure and Consequence Analysis); and second, at the scale of neighborhoods or groups of neighborhoods, referred to as focus areas. The Citywide Exposure and Consequence Analysis includes a discussion of socially vulnerable populations in the city: people who are more vulnerable to climate hazards due to life circumstances such as poverty, poor health, and limited English proficiency. The citywide assessment also considers the nature of the three climate hazards, as well as their separate and diverse expected effects on Boston's people, buildings, infrastructure, and the economy. The Exposure and Consequence Analysis for Focus Areas was developed to provide deeper insight into exposure and consequences as a result of coastal flood hazards in specific vulnerable areas within the Boston community. Climate Ready Boston is able to address coastal flood hazard for coastal focus areas due to the robust nature of the information available, quality of evaluation possible at that scale, and magnitude of expected consequences throughout this century. The following focus areas have been examined for coastal flood hazard beyond the details provided at the citywide scale:

- **Charlestown**
- **Charles River neighborhoods**[2]
- **East Boston**
- **Dorchester**
- **Downtown**
- **South Boston**
- **South End**

An eighth focus area, **Roxbury**, serves as an illustrative example of the interplay of the three hazards reviewed in this Vulnerability Assessment with multiple social vulnerability factors and their effects on collective risk and resilience planning.

[1] Both heat and stormwater flooding also have the capacity to impact the city through severe, acute events. Boston currently experiences heat indexes greater than 90 degrees more than once a year. Over time, the number of days at which this heat index is reached will continue to grow, increasing an already chronic issue. Climate Ready Boston evaluates stormwater flooding at the 10-year, 24-hour frequency event, though more and less severe and frequent events are known to occur. This evaluation is in line with the assessment led by the Boston Water and Sewer Commission, as well as the target level of performance for drainage systems within the City of Boston.

[2] The Charles River neighborhoods include Allston/Brighton, Back Bay, Beacon Hill, and Fenway/Kenmore. These neighborhoods are expected to be exposed to overtopping or flanking of the Charles River Dam.

PROCESS OVERVIEW

The Climate Ready Boston Vulnerability Assessment evaluates three climate hazards and their plausible changes over time due to climate change:

- Chronic extreme heat
- Frequent stormwater flooding
- Acute and chronic coastal and riverine flooding

Climate Ready Boston developed a methodology unique to each hazard to evaluate impacts on people, buildings, infrastructure, and the economy. Boston's socially vulnerable populations, which are less able to prepare for, adapt to, and bounce back from climate impacts, received particular attention.

Methodologies vary for each hazard due to the quality and granularity of data available. In the case of extreme heat, for instance, a detailed risk assessment of infrastructure and the economy is impractical due to data limitations. Accordingly, the impacts to people and buildings are the primary focus. In the case of the stormwater flooding, the evaluation of buildings and infrastructure is largely qualitative. In contrast, a rich coastal and riverine flooding dataset is available for multiple sea level rise conditions and coastal storm flood probabilities that can be used to quantitatively assess exposures, vulnerabilities, and consequences.[3]

[3] Quantitative results presented in this report are preliminary and are based on data with inherent uncertainties, as well as generalized assumptions, as opposed to site-specific assessment of assets, structures, and population present within specific buildings. For example, the first-floor elevation of a structure is assumed to be at grade. In actuality, many residential structures are split, and steps at grade may descend to the first floor (potentially increasing flood loss), and other structures may be elevated or flood-proofed above grade. Site-specific evaluations of vulnerability are beyond the scope of this assessment and should be reserved for detailed evaluation of specific adaptation measures. Values should be interpreted as indicators of relative risk among different areas within the city.

THE VULNERABILITY ASSESSMENT EVALUATES THESE THREE CLIMATE HAZARDS:

EXTREME HEAT

Heat is a chronic hazard, a stress that the city faces every year. As average temperatures rise and the frequency, duration, and intensity of heat waves increase, heat mortality rates will also rise. **Temperatures are hottest in areas of the city that experience the urban heat island effect, but on very hot days, the entire city is at risk for the health impacts of extreme heat,** especially those with health or other physical challenges, such as older adults or those with medical illness. The heat will increasingly stress the city's energy supply and related infrastructure as people seek ways to cool down.

FREQUENT STORMWATER FLOODING

The extent of frequent stormwater flooding[4] is expected to grow over time, further limiting access and mobility during flood events across the city. Due to limitations in available data, this study assesses frequent stormwater flooding only. Though high-severity, low-probability rain events are not assessed, the impacts of frequent flooding are informative to long-term planning as they can have broad societal effects and can be particularly disruptive for people who already face significant challenges due to poverty, illness, or other social vulnerability factors. **Frequent stormwater flooding is a citywide concern in Boston, with 7 percent of the total land area in the city likely to be exposed to the 10-year, 24-hour event as soon as the 2050s and 9 percent by the end of the century. West Roxbury, Allston, Brighton, East Boston, and South Dorchester have the largest areas of land affected by stormwater flooding, while the South End and South Boston can expect to see the greatest increase in land area exposed to stormwater flooding** as sea levels rise and precipitation events become more extreme.

[4] The Vulnerability Assessment evaluates 10-year, 24-hour storm events. It does not evaluate more severe events, like the 100-year, 24-hour storm events.

COASTAL & RIVERINE FLOODING

Coastal and riverine flooding is expected to lead to the most significant climate hazard consequences. Flooding will be concentrated in low-lying waterfront neighborhoods, particularly Charlestown, Downtown, East Boston, South Boston, and, later in the century, the South End and Dorchester. Due to sea level rise, late in the century, coastal and riverine flooding will affect Boston both during storm events and during high tides, which will cause large-scale flooding in some neighborhoods.

Building upon previous work by the City, other government agencies, and private entities, the Climate Ready Boston Vulnerability Assessment uses the best available hazard data, adjusted in some cases to align with the climate projection consensus developed by the Boston Research Advisory Group (BRAG), the first component of the Climate Ready Boston initiative (see Climate Projection Consensus chapter, p.01).

EXPOSURE, VULNERABILITY, CONSEQUENCES, AND RISK

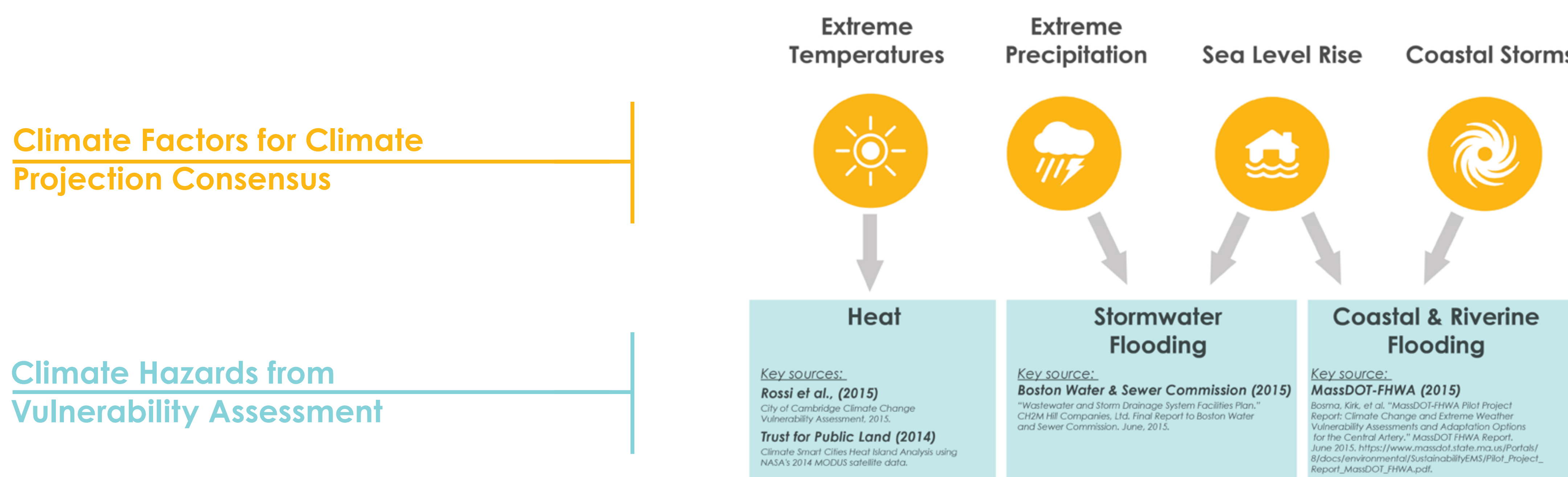
Exposure signifies people, buildings, infrastructure, and other resources (assets) that are within areas that are most likely to experience hazard impacts. Nevertheless, exposure analysis does not provide insight into the extent or severity of exposure or even whether the people, buildings, or infrastructure will experience loss, as it does not consider site specific conditions (e.g., building flood-proofing) that may prevent or limit impacts.

Vulnerability refers to how and why people or assets could be affected by a hazard or how and why the effects could be exacerbated or limited. Assessing vulnerabilities requires site-specific or demographic information, such as existing flood-proofing measures or whether people have vehicles that could facilitate evacuation.

Consequence analysis illustrates to what extent people or assets can be expected to be affected by a hazard, as a result of combined vulnerability and exposure. Consequences are qualitative and quantitative impacts to exposed and vulnerable people, buildings, or infrastructure, and many can be communicated in terms of economic losses. Categories of loss quantified for this analysis include direct physical damages to buildings (including structure, contents, and inventory damage), human impacts or stress factors (mental stress, anxiety, and lost productivity), displacement costs (the cost to relocate a business or household as a result of flood impacts), and losses to the city's economy due to business interruption. The consequence analysis also evaluates shelter needs expected as a result of a coastal flood event, but these consequences are not separately monetized.

Risk is essentially the combination of exposure, vulnerability, and consequences. Risk is often defined as the product of both the probability and consequences of an impact and is expressed in this report as annualized losses.

CONNECTING CLIMATE PROJECTIONS TO THE VULNERABILITY ASSESSMENT'S HAZARD ANALYSIS



GEOGRAPHIC VARIABILITY OF HAZARDS

Two climate hazards—extreme heat and stormwater flooding—generally pose similar threats citywide; thus, the challenges and basic principles of many preparedness efforts related to heat and stormwater hazards remain largely the same across neighborhoods. In contrast, coastal and riverine flooding hazards vary widely by neighborhood and throughout time. Possible adaptations are dependent on the location in the city, community context and the people and businesses that reside in the area, the entry point along the waterfront leading to flooding, variation in topography, and the coastal or riverine conditions defining the flood hazard (e.g., the duration of flooding).

Level of detail also varies spatially (e.g., neighborhood versus citywide) based on best available data and methodological approaches by hazard. Exposure to each hazard is assessed in the Citywide Exposure and Consequence Analysis. Coastal flood hazard details are further explored in the Exposure and Consequence Analysis for Focus Areas, which were selected for additional assessment at a more granular level due the robust nature of the information available, quality of evaluation possible at that scale, and magnitude of expected consequences throughout this century. The Roxbury neighborhood has been selected as a case study example of the interplay of multiple hazards with multiple social vulnerability factors and their effects on both collective risk and resiliency planning.

HAZARDS

A description of each of the three hazards evaluated as part of this Vulnerability Assessment, the motivation for assessing a given hazard, the Climate Ready Boston climate projections analyzed, and hazard data available from previous studies are outlined below.

EXTREME HEAT

Boston will experience both an increase in average temperatures and more extreme heat events. Heat waves can cause risks to health, but the negative consequences of heat on the population can be mitigated with effective measures to prepare individuals and communities. Heat is especially dangerous to those with health challenges, and it puts strain on the natural and built environment, including through energy demands and damage caused by heat expansion in building and road materials.

This assessment outlines anticipated increases in average temperature and extreme heat events and the impact these changes will have on public health. The Climate Ready Boston Climate Projection Consensus evaluated data from many recent studies performed across the northeast; data sources used include projections for average temperatures and heat waves, as well as analysis of the urban heat island (UHI) effect.

Locally, a heat wave is defined most often (and for the purposes of this study) as three or more days in a row with maximum ambient temperatures greater than 90 degrees Fahrenheit. The Vulnerability Assessment used data and projections created as part of the City of Cambridge Vulnerability Assessment, supplemented by the Kopp and Rassmussen 2014 projections to best understand and analyze frequency, intensity, and duration of extreme temperatures in Boston.

The Vulnerability Assessment uses the Trust for Public Land's (TPL) base heat island analysis[5] to understand future UHIs and temperature severity in Boston areas. Since extreme heat will be experienced across the city, there are no "exposure" statistics to report, and focusing only on the exposure to heat islands would be misleading; populations and infrastructure across the city will be at risk of the impacts of hotter temperatures.

Many of the consequences of extreme heat are not readily quantifiable. Instead, understanding that loss of life is a severe risk that a city or community can face, the assessment focuses on **quantifying an increase in heat mortality and analyzing qualitatively the other consequences of extreme heat, including increased morbidity (illness), increased energy use, and environmental impacts.**

STORMWATER FLOODING

For the purposes of this study, frequent stormwater flooding has been assessed using a 10-year, 24-hour design storm. Changes in frequent stormwater flooding over time were evaluated based on projected changes to extreme precipitation and sea level rise but assuming no changes to the current stormwater drainage system.[6] Even with current sea levels and precipitation intensities, Boston's existing stormwater drainage system is designed to handle 4.8 inches of rain in 24 hours[7] and can become overwhelmed by fairly frequent rain events (e.g., the 10-year, 24-hour storm, approximately 5.24 inches of rain in 24 hours[8]), leading to pooling of water on streets and localized flooding. Conveying collected stormwater will prove even more challenging with the addition of sea level rise and more intense precipitation. This design storm was selected because the Boston Water and Sewer Commission's (BWSC) Wastewater Facilities Study[9] used the storm to conduct a climate assessment; the BWSC data are the best available set of comprehensive stormwater flooding data throughout the city.[10] Additionally, the BWSC data align with the Climate Ready Boston climate projections for sea level rise (SLR) and precipitation.[11] Specifically, three BWSC 10-year, 24-hour stormwater flood extents were evaluated citywide.[12]

LIKELY YEARS OF INITIAL OCCURRENCE	VULNERABILITY ASSESSMENT SLR (ABOVE CURRENT TIDE LEVELS)	10-YEAR, 24-HOUR RAINFALL DEPTH
2030S–2050S[13]	9 INCHES	5.6 INCHES
2050S–2100S[14]	21 INCHES	5.8 INCHES
2070S OR LATER[15]	36 INCHES	6.0 INCHES

Due to model and data limitations associated with the BWSC analysis, stormwater flooding exposure is reported at the citywide scale. The Vulnerability Assessment estimates direct exposure to buildings and the residents within those buildings but does not describe impacts to individual buildings or infrastructure assets.[16] Additional qualitative assessments are made where possible. In contrast, the available coastal and riverine flooding data allow for an assessment of individual buildings and infrastructure and a more detailed discussion both at the citywide and neighborhood scale.

10-YEAR, 24-HOUR STORM

Consistent with the BWSC Wastewater Facilities Study, the Vulnerability Assessment uses the 10-year, 24-hour design storm to approximate stormwater flooding extents due to changing sea levels and extreme precipitation over time.

A 10-year storm has a 10 percent chance of being equaled or exceeded any given year. A 24-hour design condition defines the duration of intense rainfall. Though rainfall can be less or more intense, and the duration can last hours to days, only 10-year, 24-hour design storm data are available for this analysis. More intense rainfall, like 100-year events (i.e., those with a 1 percent chance of occurring in a given year), are not considered due to data limitations but are important to understanding the full spectrum of vulnerabilities related to stormwater flooding.

[5] While Climate Ready Boston has not analyzed future heat island projections in this report, Rossi et al. observed a general trend that UHIs tend to remain in place (and increase in severity) in warmer future scenarios, which were applied in this UHI analysis. UHI is understood through spatial analysis conducted by the TPL to identify specific localities in Boston that experience higher temperatures than the city average locality during days with hot temperatures. The TPL maps show relative land surface temperature data from MODIS/Aqua radiometer satellite (MODIS MYD11A2) from the warmest summer months. They identify the specific locations in urban areas that meet the characteristics of UHI isotherms and have land surface temperatures averaging at least 1.25 degrees Fahrenheit above the mean temperature for both day and night scenarios.

[6] The analysis assumes that the current stormwater drainage system remains as it is today, though the Boston Water and Sewer Commission has plans to improve the system incrementally over time.

[7] Source: Sullivan, John "Climate Adaptation Challenges for Boston's Water and Sewer Systems." Presentation for the National Association of Flood and Stormwater Management Agencies. October 15, 2014.

[8] Source: Jewell, Charlie, John Sullivan, Bill McMillin. "BWSC Climate Change Risk Assessment: Findings and Mitigation/Adaptation Strategies for Wastewater and Storm Drainage." Presentation for the NEWEA Annual Conference and Exhibit. January 28, 2015

[9] Source: "Wastewater and Storm Drainage System Facilities Plan." CH2M Hill Companies, Ltd. Final Report to Boston Water and Sewer Commission. June, 2015.

[10] BWSC examined multiple stormwater flooding conditions, including the impacts of coastal storms on stormwater flooding. Because coastal and riverine flooding is addressed separately using the recently developed MassDOT-FHWA analysis data, the BWSC data carried forward into this Vulnerability Assessment are the stormwater flooding data that combined future sea level rise and extreme precipitation conditions only.

[11] BWSC Wastewater Facilities Study data considered two climate change scenarios, B2 (medium) and A1FI (precautionary). For extreme precipitation, the BWSC medium climate scenario aligns with the BRAG moderate emissions reduction projections, while the precautionary scenario aligns with the BRAG business-as-usual emissions projections.

[12] See Appendix for a comparison of the flood data used in this analysis to current conditions, as well as a description of system current conditions.

[13] Climate condition and stormwater hazard flooding data are the BWSC Wastewater Facilities Study medium sea level rise scenario for 2035. The exact BWSC sea level rise value examined is 0.87 feet above 2010 tide levels, in combination with a 10-year, 24-hour rainfall of 5.55 inches.

[14] Climate condition and stormwater hazard flooding data are the BWSC Wastewater Facilities Study medium sea level rise scenario for 2060. The exact BWSC sea level rise value examined is 1.71 feet above 2010 tide levels in combination with a 10-year, 24-hour rainfall of 5.76 inches.

[15] Climate condition and stormwater hazard flooding data are the BWSC Wastewater Facilities Study precautionary sea level rise scenario for 2060. The exact BWSC sea level rise value examined is 2.76 feet above 2010 tide levels in combination with a 10-year, 24-hour rainfall of 6.03 inches.

[16] Per the BWSC Wastewater Facilities Study: "It is not appropriate to use [these data] for detailed analysis (i.e., at the community or parcel-level) and [these data] should not be used as the sole source of flood elevation information. It does not necessarily identify all areas subject to flooding particularly from local drainage sources of small size. Users should be aware that inundation areas are calculated by mathematical models with precision that is limited to historical calibrations."

COASTAL AND RIVERINE FLOODING

Coastal and riverine flood hazard data used in this Vulnerability Assessment define estimated flood depths and extents as a result of tide levels, riverine flows, coastal storms, and sea level rise. The flood hazard data were selected to capture a spectrum of acute events (e.g., severe coastal storms combined with sea level rise) and chronic flooding (e.g., potential frequent flooding due to high tide and sea level rise alone, without storms).

In order to define a range of possible flood conditions for Climate Ready Boston (higher probability / lower impact through lower probability / higher impact), 10 percent, 2 percent, 1 percent, and 0.1 percent annual chance flood extents and depths were generated for three sea level rise conditions using data provided by MassDOT-FHWA. The Climate Ready Boston flood data (all four probabilities) for 9 inches[17] and 36 inches[18] of sea level rise are largely identical to the MassDOT-FHWA data, and the data for 21 inches of sea level rise were created specifically for Climate Ready Boston.[19]

The Climate Ready Boston evaluation also considers flood hazards from high tides and sea level rise alone—meaning "blue sky" conditions, without storms. Because the Boston area has a large tide range, a combined sea level rise and high tide flood exposure evaluation must also consider the frequency of occurrence of tide levels. This Vulnerability Assessment combines an average monthly high tide level[20] with sea level rise to define future high-tide flooding exposure. Average monthly high tide is approximately two feet higher than the commonly used mean higher high water (MHHW, the average of the higher high water levels of each tidal day), and lower than king tides (the twice-a-year high tides that occur when the gravitational pulls of the sun and the moon are aligned).

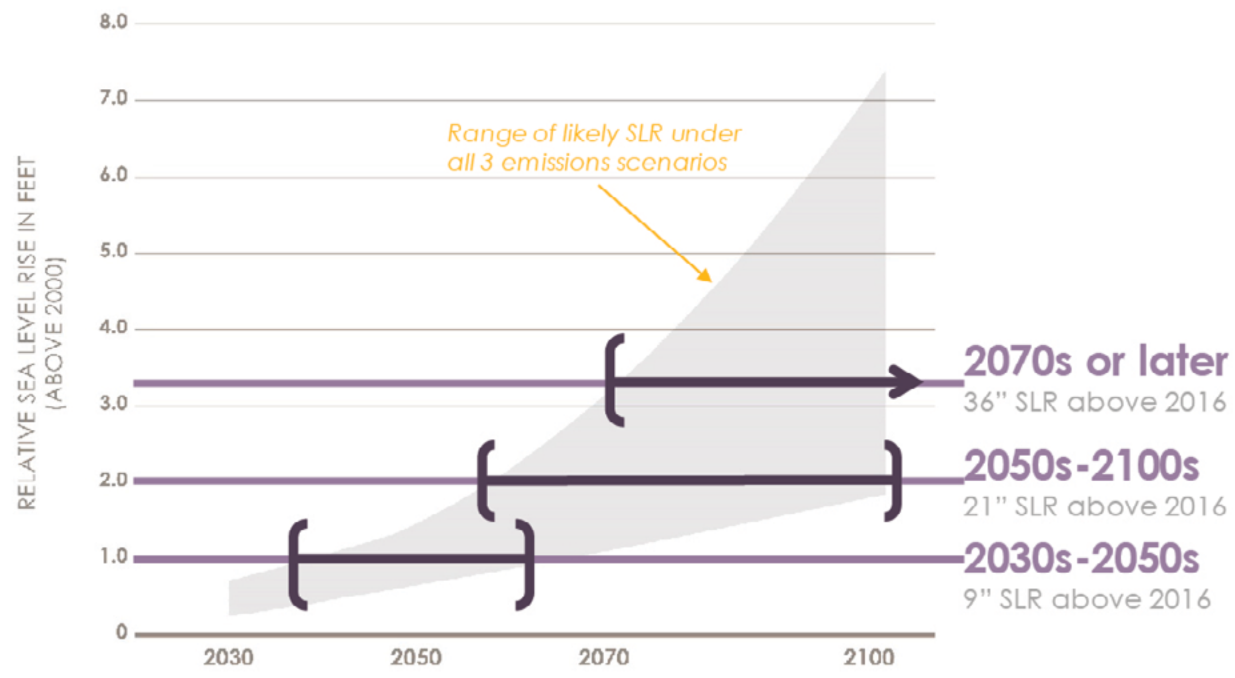
[17] Climate scenario and coastal/riverine hazard flooding data are the MassDOT-FHWA high sea level rise scenario for 2030. Actual sea level rise value is 0.62 feet above 2013 tide levels, with an additional 0.74 inches to account for subsidence.

[18] Climate scenario and coastal/riverine hazard flooding data are the MassDOT-FHWA high sea level rise scenario for 2070/intermediate sea level rise scenario for 2100. Actual sea level rise value is 3.2 feet above 2013 tide levels, with an additional 2.5 inches to account for subsidence.

[19] Data were interpolated from the MassDOT-FHWA 2030 and 2070/2100 data.

[20] Average highest tide for each month in 2015.

CLIMATE READY BOSTON SEA LEVEL SCENARIOS COASTAL AND RIVERINE FLOODING



VULNERABILITY ASSESSMENT SLR (above current sea level)	LIKELY YEARS OF INITIAL OCCURRENCE		
	Major Emissions Reduction	Moderate Emissions Reduction	Business as usual
9 inches	2030s–2050s	2030s–2050s	2030s–2050s
21 inches	2060s–2100s	2060s–2090s	2050s–2080s
36 inches	2090s OR LATER	2080s OR LATER	2070s OR LATER

SELECTION OF SEA LEVEL RISE[21] CONDITIONS

Sea levels, or the difference in elevation between the sea surface and land surface, have risen in Boston over the past century due to multiple, complex, and simultaneous processes. These processes include thermal expansion and ice-sheet melt, the gravitational effect of ice-sheet melt, ocean dynamics, and vertical land movement (such as local subsidence). From 1921 to 2015, the overall trend in sea level rise was approximately 1.1 inches per decade. From 1990 to 2010, the average rate increased to 2.1 inches of sea level rise per decade. This means that Boston's **2015 sea levels are about 3 inches higher than 2000.**

The pace of sea level rise is accelerating. Sea level rise projections by 2030 are consistent across all emissions scenarios evaluated in Climate Ready Boston, with likely sea level rise rates ranging from historic rates to 3 inches per decade (a nearly 50 percent higher rate of increase than the last two decades). Later in the century, the rate of sea level rise is expected to further accelerate, with significant variation between emissions scenarios (see the Climate Projection Consensus for more information on this topic).

- **Three sea level rise conditions have been used in the evaluation: 9 inches, 21 inches, and 36 inches *above current sea levels.***[22] These selected conditions reflect a range of sea level rise conditions likely to occur before the end of the century in the three emissions scenarios considered.
- By the end of the 2050s, **9 inches** of sea level rise is expected consistently across emissions scenarios and is likely to occur as early as the 2030s.
- In the second half of the century, **21 inches** is expected across all emissions scenarios.
- The highest sea level rise considered, **36 inches**, is highly probable toward the end of the century. This scenario has a greater than 50 percent chance of occurring within this time period for the moderate emissions reduction and business-as-usual scenarios and a nearly 50 percent chance for the major emissions reduction scenario.

[21] Relative sea level rise, including subsidence, is considered in this document. Though the term "sea level rise" is used throughout the document, this Vulnerability Assessment is referring to relative sea level rise, and not just rise in sea levels alone. Additionally, in many graphs and tables, the acronym "SLR" is used.

[22] The BRAG Climate Projection Consensus report documented sea level changes relative to a year 2000 reference level, while the Vulnerability Assessment assumes current (2016) sea levels as a reference level. Current sea levels are about three inches higher than those in 2000. See the Climate Projection Summary in this report for more information.

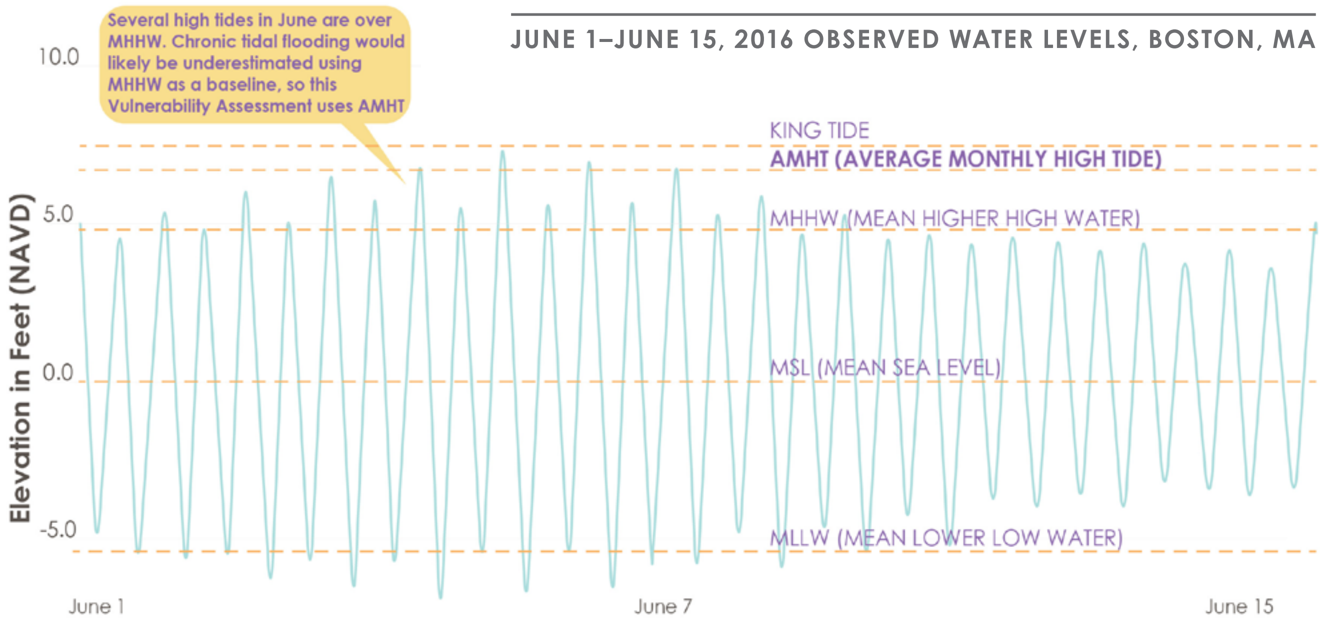
These three sea level rise conditions do not include the worst-case scenarios but instead together define a likely range before the end of the century. **Though these three scenarios are used for qualitative and quantitative assessment in this study, more severe and even worst-case sea level rise scenarios should also be considered** as part of future climate-related studies. Evaluation and design of adaptation measures should consider that more severe sea level rise conditions are possible; the BRAG's "business as usual" scenario estimates that seven feet of sea level rise is within the likely range by the end of the century.

COASTAL FLOOD HAZARD DATA

The majority of the coastal flood hazard data created as part of this assessment are a reanalysis of the coastal flood hazard data developed as part of the MassDOT-FHWA analysis.[23] In 2015, MassDOT released an analysis of coastal flood hazards using state-of-the-art numerical models capable of simulating thousands of potential nor'easters and tropical storms coincident with a range of tide levels, riverine flow rates in the Charles and Mystic Rivers, and sea level rise conditions.

The City of Boston used a similar approach and the same technical team as the MassDOT-FHWA analysis when working with the Federal Emergency Management Agency (FEMA) in the development of flood insurance rate maps (FIRM) that went into effect on March 16, 2016. The FEMA FIRMs define current flood risk from a regulatory perspective. Nevertheless, the data available from the MassDOT-FHWA analysis are used in this study because unlike the FEMA FIRMs, the MassDOT-FHWA data account for sea level rise and other climate related factors. More details can be found in the Appendix.

[23] Bosma, Kirk, et al. "MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery." MassDOT FHWA Report. June 2015. https://www.massdot.state.ma.us/Portals/8/docs/environmental/SustainabilityEMS/Pilot_Project_Report_MassDOT_FHWA.pdf.



Observation Data from NOAA Gauge Observations (Station 8443970 in Fort Point Channel)

"Average Monthly High Tide" is an average of the highest monthly tides

PERCENT ANNUAL CHANCE FLOOD VERSUS 100-YEAR FLOOD

A "1 percent annual chance flood" is a flood event that has a 1 in 100 chance of occurring in any given year. Another name for this flood, which is the primary coastal flood hazard delineated in FEMA FIRMs, is the "100-year flood." Experts prefer not to use the "100-year" term, since it gives the impression that a certain level of flooding will reliably occur once every 100 years. In fact, it has a 1 percent chance of occurring in any given year and can even occur multiple times in a single year or decade, or it can occur less frequently. Over a 30-year period, there is almost a one in three chance that a 1 percent annual chance flood will occur at least once.

Image courtesy of Sasaki

EXPOSURE AND CONSEQUENCES: AN INTRODUCTION TO THE VULNERABILITY ASSESSMENT CALCULATIONS

PEOPLE

Boston enjoys a richly diverse population; a key part of Climate Ready Boston is analyzing how climate hazards will impact Boston's residents. The Vulnerability Assessment quantifies exposures to populations as a whole, with an additional qualitative focus on vulnerable populations expected to be disproportionately affected by each hazard.

Not all residents are equally able to prepare for, adapt to, and bounce back from temperature and flood hazards. Those most vulnerable to current hazards are expected to be impacted the most as hazards worsen with climate change. Climate Ready Boston specifically considers the populations in Boston more vulnerable to these hazards. The Climate Resilience Initiatives chapter (see p.74) describes options for increasing resiliency for these groups.

Seven groups who tend to be especially vulnerable to heat and flood hazards have been considered:[24]

- Older adults (65+)
- Children
- People of color
- People with limited English proficiency
- People with low to no income
- People with disabilities
- People with chronic and acute medical illness

These groups are not necessarily independent. For example, immigrants are often those with limited English proficiency.[25] Each vulnerability can be thought of as a stressor that the individual or household experiences, limiting that person or household's ability to adapt to and absorb chronic or frequent stresses from climate hazards (e.g., heat or stormwater flooding hazards) or recover from acute events (e.g., coastal storm flooding).

Data regarding social vulnerability to climate change face some limitations; it can be difficult to differentiate between inherent challenges to socially vulnerable populations and climate-specific challenges and impacts. Similarly, solutions to create more resilient neighborhoods often overlap with solutions to strengthen the community as a whole. In-depth research into how different social vulnerabilities correlate and overlap is in somewhat early stages, making it difficult to quantify how much belonging to one or more socially vulnerable group changes the way a person is affected by climate hazards. Overlapping groups can lead to over-counting; the assessment quantifies how many people in one specific vulnerable group live in a neighborhood but not the total number of vulnerable residents, due to the potential for one individual to belong to multiple groups.

In its evaluation of exposure to and consequences of impact as a result of heat or frequent stormwater flooding, the Vulnerability Assessment takes a

SOCIAL VULNERABILITY

Social vulnerability is defined as the disproportionate susceptibility of some social groups to the impacts of hazards. These impacts could include death, injury, loss, or disruption of life or livelihood. Social vulnerability also affects a population's resilience: ability to adequately recover from or avoid impacts. Vulnerability is a function of demographic characteristics of the population, as well as environmental and community conditions such as healthcare provision, social capital, access to social networks, and social isolation.

[24] Several studies and methodologies surrounding social vulnerability informed this analysis, including the Social Vulnerability Index and a 2015 study by Dr. Atyia Martin, which used advanced Boston-specific data to assess how various determinants of social vulnerability relate to one another (co-occurrences) and to identify primary variables that capture the full range of vulnerabilities. Source: Martin, S. Atyia. "A Framework to Understand the Relationship between Social Factors That Reduce Resilience in Cities: Application to the City of Boston." International Journal of Disaster Risk Reduction 12:53–80. 2015.

[25] Ibid.

VULNERABILITY ASSESSMENT LOSS CATEGORIES

LOSS CATEGORY	LOSSES CONSIDERED	DESCRIPTION
STRESS FACTORS	• Mental stress and Anxiety • Lost Productivity	Natural disasters threaten or cause the loss of health, social, and economic resources, which leads to psychological distress. Stress factors are a product of damage to people's homes and are quantified as treatment costs and as lost income.[29]
SHELTER NEEDS	• Number of people and households in need of public shelter	Shelter needs for coastal and riverine flood events are calculated as a function of flood depth and certain social vulnerability factors, such as age and income of the affected population.
DIRECT PHYSICAL DAMAGES TO BUILDINGS	• Structure Damage • Content Loss • Inventory Loss	Direct physical damages include the destruction and degradation of buildings as a result of coastal or riverine flooding and are quantifiable as monetary losses.
DISPLACEMENT	• One time displacement and relocation costs	Displacement costs are associated with moving a household or a business to a new location and resuming activity in that new location.

more qualitative approach, though it also explores numbers and demographics of people expected to be affected. The coastal and riverine flood-risk evaluation considers potential consequences in a more quantitative fashion. It looks not just at the number of people exposed or expected to be displaced as the result of an event but reviews expected economic costs resulting from mental stress and anxiety as well as lost productivity. Shelter needs expected for each evaluated event in each sea level rise scenario have been calculated based on the following factors:[26]

- Expected flood depths within occupied structures
- Population residing in those structures
- The share of the current population within a given area that is identified as low to moderate income or as older adults

Mental stress and anxiety calculations are based on the percent share of the impacted population expected to seek mental health treatment as a result of disruption caused by direct physical flood impacts to the structures within which they reside, as well as the expected costs of such treatment.[27] Lost productivity[28] refers to lost work productivity as a result of mental stress and anxiety alone, and it is calculated based on expected earnings lost over time as a result of decreased work productivity or performance. Both figures only consider impacts for the 30-month period following a flood event and are considered highly conservative (low estimates), particularly given that results only consider the portion of the population expected to actively seek treatment and not all of those who will likely experience some sort of impairment as a result of the stress from an event.

Additional consequence calculations related to the city's population are captured within the coastal and riverine evaluations for buildings and the economy and should be considered when planning for both the general population and vulnerable people. Such calculations include relocation and displacement costs as well as potential job loss. More information on these topics is provided below.

BUILDINGS

Climate Ready Boston developed an understanding of both exposure and potential consequences of climate hazard impacts to the city's current building stock through a number of steps described in detail in the Appendix and briefly described here. First, Climate Ready Boston compiled a comprehensive building stock inventory from a variety of sources. The information gathered from these sources was reconciled and reviewed for overlap, inaccuracies, and need for clarity. Data fields used for the evaluation were extensive and include such structure characteristics as location, footprint, use, number of stories, and real estate market value. Based on the location, use, size, and type of structure, analysts developed building construction and replacement costs,[30] one-time disruption costs[31] for the structure, and expected contents and inventory[32] as well as rental rates[33] and other assumptions that would be needed to understand potential financial consequences in the case of flood impacts. Grade-elevation data was combined with the building stock in order to analyze the extent and depth of flooding that could occur at and within each structure based on the flood hazard data described above.

Flood exposure was determined by cross-referencing structure location data with stormwater, coastal, and riverine flood hazard overlays and has been calculated based on structures shown to currently exist within areas identified as future flood hazard areas. Exposure results for flood hazard can be reported based on any number of structure characteristics and are provided in this report by number and type of structures exposed, exposed square footage, and real estate market value exposed. Exposure to heat hazard is pervasive across the city, with higher heat indexes expected within urban heat islands.

Consequences of coastal and riverine flood damage were evaluated based on depth damage functions developed by the United States Army Corps (USACE) for this region following Hurricane Sandy.[34] Flood depths at each structure are cross-referenced with depth damage functions that provide expected percent loss and expected displacement times (number of days that the structure is expected to be uninhabitable) for the structure.[35] Costs of displacement[36] and direct physical damage to buildings were then calculated based on percent loss and displacement time combined with structure replacement costs and disruption costs and rental rates, respectively.

[26] Methodology is detailed in the Appendix and follows process described in FEMA's Hazus Flood Technical Manual 2.1. Source: "Hazus Flood Technical Manual." Federal Emergency Management Agency. Hazushtt

[27] See Appendix for detailed methodology and sources.

[28] Both mental stress and anxiety and lost productivity are calculated using FEMA methodologies approved for benefit-cost analyses to federal funding for mitigation projects. See Appendix for detailed methodology and sources. Source: "Final Sustainability Benefits Methodology Report." Federal Emergency Management Agency. August 23, 2012. /pii/S22124291400119

[29] Values are considered conservative as they only incorporate the percent of the population expected to seek treatment, as opposed to the entire population expected to experience mental stress and anxiety. Further, only near-term effects are evaluated. Refer to the Appendix for a more detailed description of the approach.

[30] Building replacement values per square foot were obtained by analysts from RSMeans2016 square footage costs for building types in the Boston area. See Appendix for more detail.

[31] One-time disruption costs are essentially costs to move people or contents from one location to another and have been developed using FEMA Hazus values. See Appendix TBD for more detail.

[32] The contents replacement value is based on the contents-to-structure ratio values (CSRV) for residential and non-residential structures from data obtained through surveys in the West Shore Lake Pontchartrain Hurricane and Storm Damage Risk Reduction Study. Source: "West Shore Lake Pontchartrain Hurricane and Storm Damage Risk Reduction Study—Final Integrated Feasibility Study Report and Environmental Impact Statement." USACE. November 2014.

[33] Based on 2016 local market rates. See Appendix for more detail.

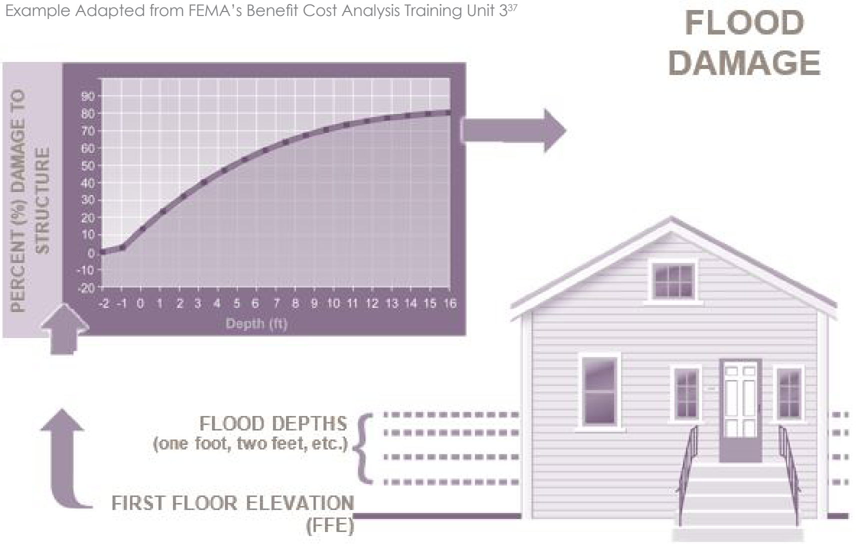
[34] Source: "North Atlantic Coast Comprehensive Study (NAACS)." U.S. Army Corps of Engineers. http://www.nad.usace.army.mil/CompStudy.

[35] One-time disruption costs are essentially costs to move people or contents from one location to another and have been developed using FEMA Hazus values. See Appendix TBD for more detail.

[36] Displacement or relocation costs are calculated based on numerous factors to include local rental rates, owner occupancy rates, structure flood depths, and others. See Appendix for full methodology.

DEPTH DAMAGE FUNCTIONS IN PRACTICE

Example Adapted from FEMA's Benefit Cost Analysis Training Unit 3[37]



Consequences of impact from heat- and stormwater-related flood hazards are assessed more qualitatively based on structure types and occupancies, as well as lessons learned. For example, certain structures are more likely to experience stress to their power supply as a result of excessive heat.

INFRASTRUCTURE

Infrastructure refers to facilities and assets that provide a public service to the City of Boston and its population. Infrastructure may be publicly or privately owned and operated and include the following, for example:

- Critical facilities, such as water treatment facilities and generating plants
- Transportation infrastructure, such as roads, bridges, and public transportation
- Essential facilities, such as hospitals and emergency operations centers
- Public facilities, such as schools and civic structures

Climate Ready Boston developed a detailed asset inventory to capture infrastructure and to supplement the general building stock described above. This combined inventory was based on over 130 separate datasets from a variety of sources (see Appendix for more detail). This dataset was merged with the general building stock, where appropriate, in order to fill in data gaps and confirm property uses. Members of the Infrastructure Advisory Group (IAG) supported the identification of infrastructure assets, as well as relationships and interdependencies between different assets and entities, individual and system vulnerabilities, and existing resiliency measures in place or planned.

The infrastructure analysis for stormwater and coastal and riverine flooding presents exposure statistics accompanied by largely qualitative descriptions of potential impacts that may result from service interruptions, including interdependencies between different infrastructure networks. Due variably to data limitations or privacy and security concerns, the Vulnerability Assessment does not include site-specific information necessary to individually assess infrastructure vulnerability.[38] Only direct physical damages to buildings have been captured for coastal and riverine flood hazard using the method explained above in the Buildings section, with potential impacts to service and line routes (such as transportation, pipelines, electrical lines) described qualitatively.[39] Heat hazard vulnerability is assessed qualitatively and refers predominantly to impacts on energy infrastructure as well as public and other facilities without air conditioning or that may house vulnerable populations (such as nursing homes or public housing).

While the focus of this analysis is on impacts to Boston's infrastructure, much infrastructure is systemic in nature and will have broader regional impacts that need to be considered in future planning efforts. Similarly, the impacts of regional infrastructure on Boston's people and economy should be considered in future efforts.

[37] It should be noted that calculations typically involve the 10 percent, 2 percent, 1 percent, and 0.2 percent annual chance events. Climate Ready Boston has substituted the 0.2 percent annual chance event with the 0.1 percent annual chance event in order to understand impacts at that severity of storm. As such, damage-cost calculations may be conservative compared to if the 0.2 percent annual chance had been incorporated.

[38] At a minimum, site-specific information needed to make conclusions about asset or system vulnerability include the critical flood elevation and any mitigation or emergency protection measures in place.

[39] It should be noted that service loss can be quantified.

SUPPORT FROM INFRASTRUCTURE AND COMMUNITY LEADERS

Infrastructure and community stakeholders supported the development of the Vulnerability Assessment and climate resilience initiatives through participation in the IAG and the Community Climate Resilience Focus Groups.

Infrastructure Advisory Group: IAG members included representatives from the following:

- Utility companies
- Hospitals, including Medical and Scientific Community Organization, Inc. (MASCO)
- Universities
- Public agencies, such as the Massachusetts Port Authority (Massport), MassDOT, Boston Housing Authority, and the Boston Water and Sewer Commission.
- City agencies such as the Department of Public Works (DPW), the Parks and Recreation Department (BPRD), the Boston Transportation Department (BTD), the Boston Conservation Commission, the Boston Public Health Commission, and the Commission for Elderly Affairs

Through a series of group planning discussions and workshops, IAG members supported the process by providing insight on the greater Boston area infrastructure (e.g., transportation, utilities, buildings, environmental and recreational assets, public housing, and schools) and key interdependencies between different types of infrastructure. Cascading impacts of interruption in the transportation network rose as a major concern across IAG members from all sectors.

Community Climate Resiliency Focus Group: Focus group members included representatives from the following:

- Community and neighborhood development corporations (e.g., the Neighborhood of Affordable Housing [NOAH])
- Government agencies and commissions (i.e., the Boston Public Health Commission) and the Boston Elderly Commission)
- 100 Resilient Cities Steering Committee and Working Group (led by City of Boston Chief Resilience Officer Dr. Atyia Martin)

Goals included providing input to the Vulnerability Assessment and Climate Resilience Initiatives and providing an opportunity for groups to learn from one another. Discussions focused on community infrastructure, ongoing resilience work, and opportunities for partnerships on implementation of community initiatives. Key findings included the importance of sensitivity around mapping efforts and the need to be equitable when prioritizing climate readiness solutions.

CALCULATING BUSINESS INTERRUPTION CONSEQUENCES

LOSS CATEGORY	LOSSES CONSIDERED	DESCRIPTION
BUSINESS INTERRUPTION	• Loss of Employment • Output Loss	Business interruption is associated income lost as a result of an event that disrupts the operations of the business or the removal of a piece of real estate, both rental and sale properties, from the market as a result of disaster impacts.

ECONOMY

Impacts to people, structures, and infrastructure as a result of climate hazards can also disrupt the broader Boston economy. Severe impacts can have regional, national, and even international consequences. As a result, Climate Ready Boston has sought to quantitatively capture the potential impacts of business interruption within Boston as a result of coastal and riverine flooding, although results are conservative (low estimates). Calculations use a combination of expected building restoration times sourced by FEMA, output and employment values by zip code for Suffolk County from 2014 (most recent available data), and input output modeling through IMPLAN.[40] Only loss impacts within the city are considered, and restoration times used to determine business interruption assume only floors of the structure that are directly impacted experience disruption. It further assumes that all businesses will eventually reopen and that all real estate will return to value production. It reality, almost 40 percent of small businesses never reopen following a disaster.[41]

Exposure and consequences to the city's economy as a result of heat- or stormwater-related flood hazard is explored qualitatively.

[40] Detailed methodology provided in the Appendix.

[41] Source: "National Flood Insurance Program: Protecting Your Business." Federal Emergency Management Agency. http://www.fema.gov/protecting-your-businesses.

REPORTING OF EXPECTED LOSSES AS A RESULT OF COASTAL AND RIVERINE FLOODING

All loss estimations are reported by imposing future climate conditions on the present population and built environment. Neither population nor development have been projected into the future.

Loss estimations for people, property, and the economy presented in this assessment are reported both as one-time costs by event in total, by loss category, and as an annualized value for each sea level rise condition.[42] Annualized values represent the total of the product of single losses expected for each projected sea level rise condition and its chance of occurring in any given year.[43] This method facilitates resiliency planning by allowing for comparison across areas and events, as well as expected losses in each sea level rise scenario.

[42] Annualized values consider four of the five frequencies considered in this Vulnerability Assessment, including the 10 percent, 2 percent, 1 percent, and 0.1 percent annual chance flood. Direct damages for each of the flood frequencies for one sea level rise condition were multiplied by their percent chance of occurrence and then added together to yield the annualized value for one sea level rise condition. Thus annualized values do not consider frequent flood events such as high tides or storms with a chance of occurrence greater than 10 percent.

[43] Annualized losses should not be interpreted as the losses expected annually. Refer to the Appendix for a more detailed description of the approach taken to evaluate damage factors.

PROBABILITY TIMES CONSEQUENCE

Annualizing losses is one method used to "normalize" results of an evaluation (or even historical losses) in order to communicate risk. In fact, the definition of "risk" is often communicated as "probability times consequence"; this is exactly how annualized losses are calculated. Annualized losses can be used to compare the impacts of different events across time for mitigation-planning purposes and can even be used to compare the effects of entirely different hazards (so long as a probability of impact and costs of such impact can be derived). Expected relocation costs within the city as a result of 9 inches of sea level rise (near-term sea level rise scenario) can be used to illustrate this point:

By annualizing the losses of this event, it becomes apparent that the risk (probability times consequence) associated with the 10 percent annual chance event is higher than the lowest probability event evaluated, despite the fact that one-time event costs for the 10 percent chance are expected to be significantly lower. This information informs the resiliency planner that, in combination with other factors, properties within the 10 percent annual chance flood area should perhaps be prioritized for action prior to those at risk only to lower-probability events.[44]

[44] Risk prioritization should take into consideration a variety of factors.

ANNUALIZATION OF ESTIMATED RELOCATION COSTS FOR THE 9-INCH SEA LEVEL RISE SCENARIO

EVENT	ONE-TIME EVENT CONSEQUENCES	PROBABILITY percent annual chance	ANNUALIZED probability x consequence
10% *high probability*	$12,000,000	10%	$1,200,000
2%	30,500,000	2%	$600,000
1% *lower probability*	$35,600,000	1%	$400,000
0.1% *very low probability*	$155,200,000	0.1%	$200,000
Total	*cannot be calculated*	-	$2,400,000

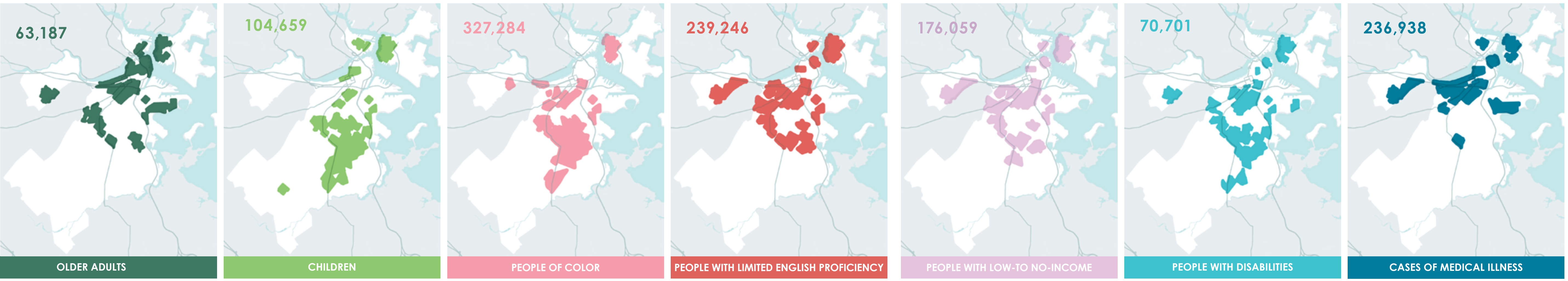
The one-time economic consequences are larger for lower probability storms.

When the frequency of occurrence is considered, the total economic cost of high probability events is significantly higher. These events have a lower cost each time they occur, but occur much more frequently.

SOCIAL VULNERABILITY

CONCENTRATIONS OF SOCIALLY VULNERABLE POPULATIONS[45]

Social vulnerability is defined as the disproportionate susceptibility of some social groups to the impacts of hazards, including death, injury, loss, or disruption of livelihood.



Numbers show a representation of citywide populations or cases.

KEY VULNERABILITIES BY POPULATION GROUP

OLDER ADULTS

Older adults (those over age 65) have physical vulnerabilities in a climate event; they suffer from higher rates of medical illness than the rest of the population and can have some functional limitations in an evacuation scenario, as well as when preparing for and recovering from a disaster. Furthermore, older adults are physically more vulnerable to the impacts of extreme heat. Beyond the physical risk, older adults are more likely to be socially isolated. Without an appropriate support network, an initially small risk could be exacerbated if an older adult is not able to get help.

CHILDREN

Families with children require additional resources in a climate event. When school is cancelled, parents need alternative childcare options, which can mean missing work. Children are especially vulnerable to extreme heat and stress following a natural disaster.

PEOPLE OF COLOR

People of color make up a majority (53 percent) of Boston's population. People of color are more likely to fall into multiple vulnerable groups as well. People of color statistically have lower levels of income and higher levels of poverty than the population at large. People of color, many of whom also have limited English proficiency, may not have ready access in their primary language to information about the dangers of extreme heat or about cooling center resources. This risk to extreme heat can be compounded by the fact that people of color often live in more densely populated urban areas that are at higher risk for heat exposure due to the urban heat island effect.

PEOPLE WITH LIMITED ENGLISH PROFICIENCY

Without adequate English skills, residents can miss crucial information on how to prepare for hazards. Cultural practices for information sharing, for example, may focus on word-of-mouth communication. In a flood event, residents can also face challenges communicating with emergency response personnel. If residents are more socially isolated, they may be less likely to hear about upcoming events. Finally, immigrants, especially ones who are undocumented, may be reluctant to use government services out of fear of deportation or general distrust of the government or emergency personnel.

PEOPLE WITH LOW-TO NO-INCOME

A lack of financial resources impacts a household's ability to prepare for a disaster event and to support friends and neighborhoods. For example, residents without televisions, computers, or data-driven mobile phones may face challenges getting news about hazards or recovery resources. Renters may have trouble finding and paying deposits for replacement housing if their residence is impacted by flooding. Homeowners may be less able to afford insurance that will cover flood damage. Having low or no income can create difficulty evacuating in a disaster event because of a higher reliance on public transportation. If unable to evacuate, residents may be more at risk without supplies to stay in their homes for an extended period of time. Low- and no-income residents can also be more vulnerable to hot weather if running air conditioning or fans puts utility costs out of reach.

PEOPLE WITH DISABILITIES

People with disabilities are among the most vulnerable in an emergency; they sustain disproportionate rates of illness, injury, and death in disaster events.[46] People with disabilities can find it difficult to adequately prepare for a disaster event, including moving to a safer place. They are more likely to be left behind or abandoned during evacuations. Rescue and relief resources—like emergency transportation or shelters, for example—may not be universally accessible. Research has revealed a historic pattern of discrimination against people with disabilities in times of resource scarcity, like after a major storm and flood.

[45] Socially vulnerable populations were mapped by number of people per land acre in each census tract in the City of Boston. Census tracts whose concentrations of vulnerable populations in each group fall in the top quartile (25 percent) of census tracts are highlighted in the series of maps.

[46] For example, research indicates the mortality rate among people with disabilities was twice that of the rest of the population during the 2011 Japan earthquake and tsunami.

SOCIALLY VULNERABLE GROUPS BY NEIGHBORHOOD

		OLDER ADULTS		CHILDREN		PEOPLE OF COLOR		PEOPLE WITH LIMITED ENGLISH PROFICIENCY[47]		LOW-TO NO-INCOME		DISABILITY		MEDICAL ILLNESS[48]	
COMMUNITY	**TOTAL POPULATION**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**
Allston/ Brighton	75,000	6,100	8%	4,600	6%	25,400	34%	9,700	13%	21,000	28%	6,200	8%	29,200	n/a
Back Bay/ Beacon Hill	22,600	2,800	12%	1,900	8%	3,600	16%	600	3%	2,600	11%	1,000	5%	9,500	n/a
Charlestown	16,400	1,800	11%	3,300	20%	4,000	24%	1,600	10%	4,200	25%	1,500	9%	6,500	n/a
Dorchester	87,400	8,500	10%	21,000	24%	62,500	72%	35,100	40%	26,600	30%	12,400	14%	31,800	36%
Downtown	30,000	4,100	14%	2,000	7%	9,400	31%	4,000	13%	6,800	23%	2,600	9%	12,400	n/a
East Boston	40,500	4,100	10%	8,700	21%	25,500	63%	17,400	43%	13,700	34%	5,200	13%	14,800	n/a
Fenway/ Kenmore	44,300	2,100	5%	600	1%	14,400	33%	3,700	8%	11,200	25%	2,700	6%	16,000	n/a
Harbor Islands	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hyde Park	32,300	4,200	13%	7,000	22%	23,200	72%	4,600	14%	5,700	18%	3,800	12%	12,500	n/a
Jamaica Plain	42,100	4,100	10%	6,300	15%	19,200	46%	4,900	12%	14,500	34%	4,200	10%	16,400	n/a
Mattapan	33,700	3,900	11%	9,600	29%	32,100	95%	5,800	17%	11,900	35%	6,000	18%	12,500	n/a
Roslindale	37,700	3,800	10%	7,100	19%	16,700	44%	5,400	14%	6,800	18%	4,100	11%	12,500	n/a
Roxbury	71,600	5,800	8%	16,700	23%	59,200	83%	11,400	16%	27,700	39%	10,400	15%	24,000	n/a
South Boston	31,800	3,200	10%	4,900	15%	7,100	22%	2,600	8%	8,200	26%	3,000	9%	13,500	n/a
South End	38,600	3,300	9%	4,900	13%	16,500	43%	5,800	15%	11,600	30%	4,300	11%	12,800	n/a
West Roxbury	30,400	5,400	18%	6,100	20%	8,100	27%	3,000	10%	3,500	11%	3,000	10%	12,400	n/a
Boston Total	634,400	63,200		104,700		327,300		98,200		176,100		70,700		236,900	
Percent of Boston	100%	10%		17%		52%		15%		28%		11%		37%	

CASES OF MEDICAL ILLNESS

Symptoms of existing medical illnesses are often exacerbated by hot temperatures. For example, heat can trigger asthma attacks or increase already high blood pressure due to the stress of high temperatures put on the body. Climate events can interrupt access to normal sources of healthcare and even life-sustaining medication. Special planning is required for people experiencing medical illness. For example, people dependent on dialysis will have different evacuation and care needs than other Boston residents in a climate event.

NEIGHBORHOOD VULNERABILITY AND CONNECTIVITY

The Vulnerability Assessment analyzes personal characteristics (like income or race) that heighten vulnerability in a climate event and also considers vulnerabilities that occur at a neighborhood scale. If a neighborhood has less access to a certain resource, its residents can be even more vulnerable. **Neighborhoods need redundancy in their resource networks** in the same way that individuals do.

Communities with overlapping vulnerabilities are at greater risk. Risk is increased even further in the context of chronically under-resourced neighborhoods.

Neighborhood connectivity is a significant factor in community resilience. Neighborhoods that are less well served by public transit or with fewer road connections overall are more vulnerable in a climate event. If a neighborhood only has one bus or subway line connecting it to the transportation system, residents who depend on transit can more easily be cut off from their employment or healthcare. The GoBoston 2030 planning effort is evaluating and planning for Boston's neighborhood connectivity.

Neighborhood connectivity spans more than just transportation access; connections between people also create more resilient communities. **Strong community organizations reduce risk from social isolation and connect residents to resources and information regarding climate change impacts.** Limited access to resources at a neighborhood scale can also exacerbate social vulnerability. East Boston, for example, has high concentrations of medical illness but no hospitals. If the tunnels and bridges became inaccessible in a flood event, those in need of acute medical care could be less able to access it; access to much-needed medications has historically been an issue in large coastal flood events.

The daily stresses socially vulnerable residents face can also make recovery and adaptation more difficult. For example, residents living in an area without a grocery store may have less access to healthy food. **In such areas, classified as "food deserts," residents may face challenges to eating healthily on a daily basis as well as acquiring adequate food supplies for sheltering in place in a climate event.** Boston's food deserts include the Seaport, Roslindale, East Boston, Roxbury, and West Roxbury.[49]

[47] "People with limited English proficiency" = ACS survey respondents who indicated they speak English less than "very well."

[48] Health data at the local level in Massachusetts not available beyond zip codes. EASI modeled the health statistics for the U.S. population based upon age, sex, and race probabilities using U.S. Census Bureau data. The probabilities are modeled against the census and current-year and five-year forecasts. "Medical illness" is the sum of asthma in children, asthma in adults, heart disease, emphysema, bronchitis, cancer, diabetes, kidney disease, and liver disease. A limitation is that these numbers may be over-counted as the result of people potentially having more than one medical illness. These statistics reflect the number of incidences of each illness, not the number of residents. Neighborhood percentages are not available due to potential for over-counting.

[49] Food deserts are areas located greater than one mile away from a grocery store. Source: "Food Access Research Atlas." USDA Economic Research Service.

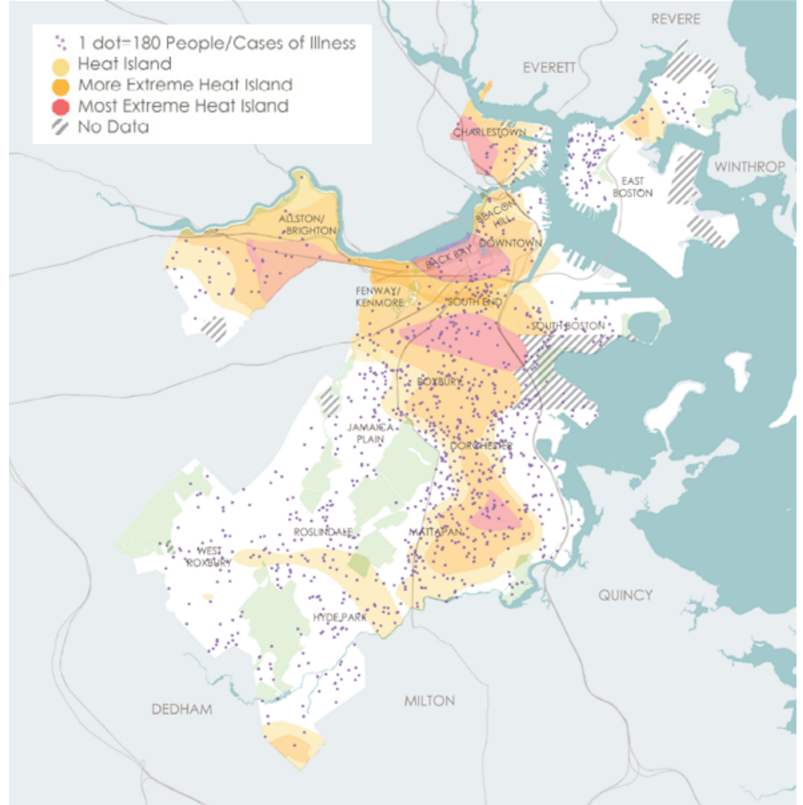
EXPOSURE AND CONSEQUENCE ANALYSIS

OVERVIEW

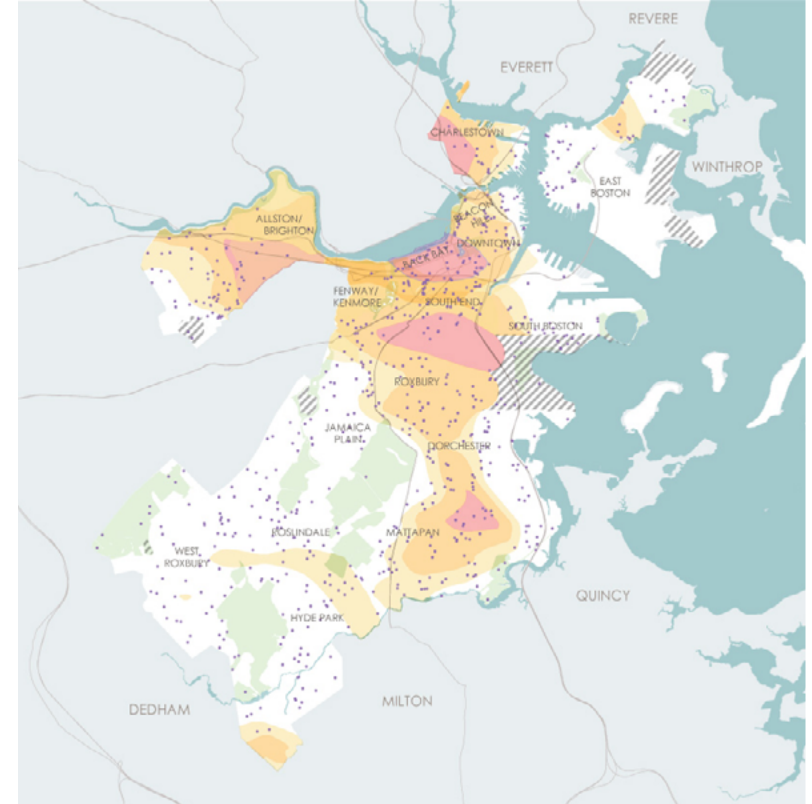
The citywide findings of the Vulnerability Assessment are summarized within this section. Based on the hazard data and methodologies previously discussed, the exposures and consequences of all three hazards are presented and compared by neighborhood. The findings for each hazard are organized based on expected impacts to people, buildings, infrastructure, and the economy. Where possible, quantitative analyses were conducted, though due to limitations in the available data, some findings only include a qualitative assessment of exposure.

This section includes analyses of the following:

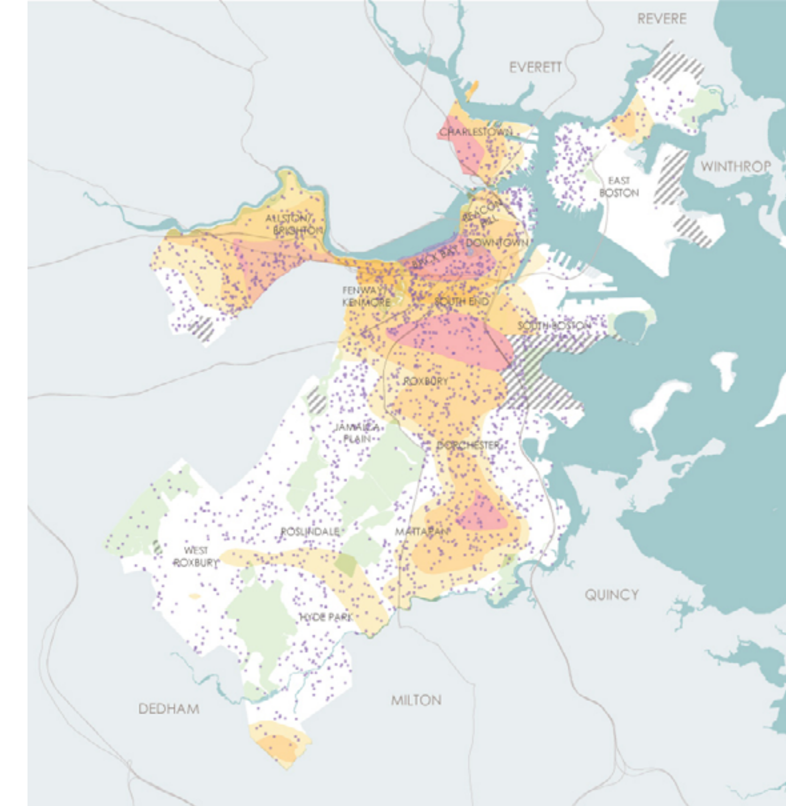
1. **Extreme Heat:** Public health and other impacts of rising temperatures
2. **Stormwater Flooding:** Quantitative and qualitative impacts on people, buildings, infrastructure, and economy
3. **Coastal and Riverine Flooding:** Quantitative and qualitative impacts on people, buildings, infrastructure, and economy



CHILDREN AND HEAT ISLAND EXPOSURE



OLDER ADULTS AND HEAT ISLAND EXPOSURE



MEDICAL ILLNESS AND HEAT ISLAND EXPOSURE

EXTREME HEAT

PEOPLE

Heat impacts are some of the most well-understood, measurable, and preventable impacts of climate change on human health.

Negative health impacts often accompany extreme heat. These consequences may include direct loss of life, increases in respiratory and cardiovascular diseases, and challenges to mental health. Weather and climate can also influence health stressors, such as air pollution and vector-borne diseases. Given the steady rise in temperatures that has been occurring in Boston—1.8 degrees Fahrenheit since 1970 (see Climate Projection Consensus within this report)—it is probable that corresponding health risks will become an even greater challenge in the future. Climate Ready Boston examined *current* climate health risks faced by Boston and considered how climate change may worsen these risks. The assessment draws on related assessments completed over the past several years.

While some health impact pathways are rather direct—such as the immediate consequences of high temperature or severe storms—most operate through complex systems involving urban land use, infrastructure, ecology, and other systems. Compromised infrastructure can magnify health vulnerabilities. For example, air conditioning requires reliable delivery of electricity, which, in turn, depends on the integrity of the electrical grid system and associated power-generating facilities. Access to healthcare services depends on a functioning transportation system. Thus, understanding the impact that future extreme weather events may have on health in Boston requires considerations of the vulnerabilities of critical infrastructure systems.

Heat extremes can cause death in addition to exacerbating chronic health conditions and disease. Emergency room visits and hospital admissions increase during heat waves. Consequences of heat are some of the most well-understood, measurable, and preventable impacts of climate change on human health. While everyone is vulnerable when temperatures spike, some members of the population are particularly vulnerable, including older adults (especially if living alone), the very young, low- and no-income residents,

The maps above show both daytime and nighttime heat islands as measured by changes in land surface temperature across the City of Boston. The dots help show concentrations of populations vulnerable to heat.

Some members of the population are particularly at risk when temperatures spike, including older adults, the very young, outdoor workers, and those with pre-existing health conditions.

outdoor workers, and those with preexisting chronic diseases.[50] In addition to these individual characteristics, research shows that living in neighborhoods with less tree canopy leads to greater risk.[51]

The link between less tree canopy and warmer temperatures in urban neighborhoods is part of the "heat island effect." The concept of the heat island effect refers to the higher temperatures observed in city centers as compared with surrounding regions; these higher temperatures are particularly hazardous at nighttime, when it is important for the body to cool off.

Most of the scientific evidence on the health effects of heat has focused on increases in daily death counts during and following extreme heat events. **Even a single day of high temperatures may increase death rates, but a sequence of hot days, as in the case of a heat wave, brings even more risk.** Extremes of heat will become more severe and more prolonged and extend into the spring and fall seasons, leading to greater exposures of vulnerable people. This exposure may be exacerbated given the aging of the population.

Morbidity and mortality effects of heat may be especially severe if the power goes out during an extreme heat event. Power failures are more likely during heat waves due to the increased demand for electric power for air conditioning, as well as the added stress of the heat on mechanical and electrical assets. At the same time, air conditioning provides important protection from exposure to extreme heat, especially for those who are most vulnerable. The loss of power during extreme events, which may be more likely with climate change, could significantly amplify heat-related health impacts in the future.

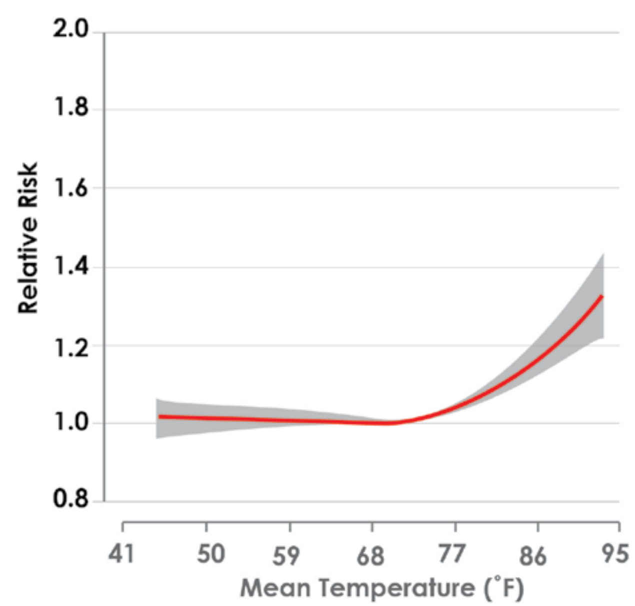
50 Source: Kinney et al., "Approaches for Estimating Effects of Climate Change on Heat-Related Deaths: Challenges and Opportunities." Environmental Science and Policy 11, 2008. Note: data for medically ill people double-counts people with multiple illnesses and thus represents total cases of medical illness of various types as opposed to a total number of people.

51 Source: Madrigano et al., "A Case-Only Study of Vulnerability to Heat Wave–Related Mortality in New York City (2000–2011)." Environmental Health Perspectives 123, no. 7. July 2015.

Researchers at Columbia University examined the potential future health impacts from warming temperatures by linking together future climate projections with information on the health responses that occur in a city when temperatures increase.[52] The historical relationship[53] between heat and deaths in the summer in Suffolk County, Massachusetts,[54] shows that death rates increased significantly with high temperatures. The analysis projected future health impacts for future temperatures in the 2020s, 2050s, and 2080s.

Since climate change will be affected by greenhouse gas emissions now and into the future, and projected emissions are uncertain, moderate upper- and lower-bound greenhouse gas projections were used to drive the climate models.[55] The following figure shows annual heat-related mortality rates for Boston.

MORTALITY RATE RELATIVE RISK BY TEMPERATURE



The figure shows the way that historical death rates from the baseline period of 1985–2006 changed as a function of temperature. A relative risk of 2.0, for example, would indicate that the heat-related mortality rate for a day of that temperature would be twice as high as a normal (1.0) day.

52 Source: Petkova et al., "Projected Heat-Related Mortality in the U.S. Urban Northeast." International Journal of Environmental Research and Public Health. 2013. doi: 10.3390/ijerph10126734.

53 Using daily data from 1985 to 2006.

54 Suffolk County includes the cities of Boston, Revere, Chelsea, and Winthrop.

55 Values derived from a combination of multiple climate studies. See the Climate Projection Summary in this report for more information.

56 The high-emissions scenario assumes the continuation of business as usual (no reduction in greenhouse gas emissions).

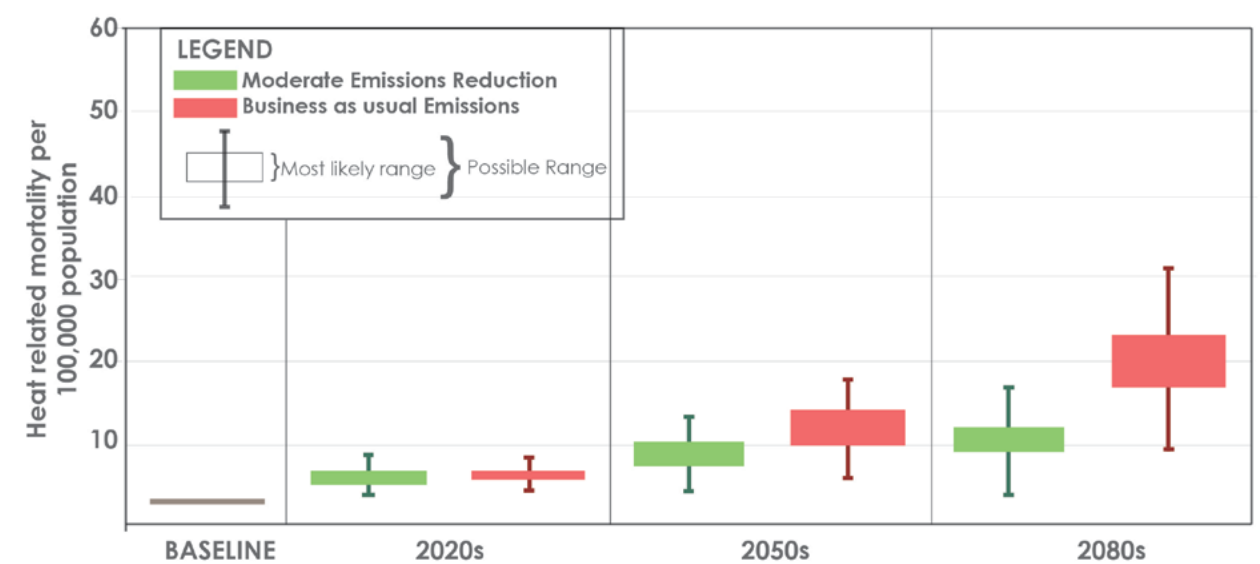
In the baseline period (1985–2016), heat-related mortality rates were estimated to be 2.9 per 100,000 people in Boston. During the 2020s, median heat-related mortality rates for the low and high GHG emission scenario are expected to be 5.9 and 6.5 per 100,000, respectively.[56] By the 2050s, Boston could experience median mortality rates of 8.8 and 11.7 per 100,000, for the low and high scenarios, respectively. By the 2080s, the median heat-related mortality rates will increase to 10.5 and 19.3 per 100,000.

Air pollution in Boston is negatively impacted by rising average temperatures.

Boston currently faces challenges in keeping levels of air pollution below health-based standards, especially for ozone and fine particulate matter (PM2.5). Boston's challenges with these pollutants are also related to its position downwind of much of the urban northeast corridor, along with power plants and factories throughout the mid-western states.

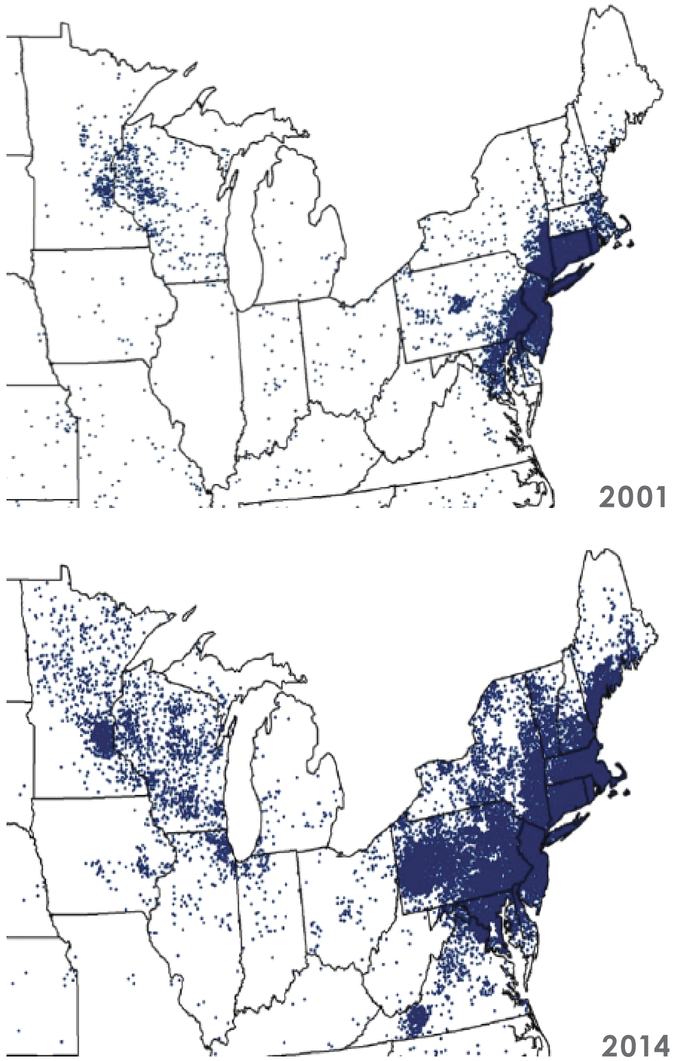
Ozone is a strong oxidant gas that occurs at high levels during the warm half of the year and is the major contributor to urban smog. Ozone exacerbates respiratory illnesses like asthma and has also been linked with premature deaths in cities. PM2.5 measures the quantity of tiny, invisible particles suspended in the air due to emissions from a wide variety of sources. Combustion of fossil fuels (e.g., from cars, trucks, furnaces, or power plants) produces large amounts of toxic PM2.5 emissions. PM2.5 exposure over the long term contributes to the development of heart and lung diseases, similar to cigarette smoking.

PROJECTED ANNUAL HEAT-RELATED DEATHS PER 100,000 POPULATION



Baseline (1985–2016) and projected future annual heat-related mortality rates for Boston according to 33 global climate models and two greenhouse gas scenarios.

Mortality rates due to extreme heat are expected to triple with the impacts of climate change in Boston.



CHANGES IN LYME DISEASE CASE REPORT DISTRIBUTION

Maps show the reported cases of Lyme disease in 2001 in 2014 for the areas of the country where lyme disease is most common (the Northeast and Upper Midwest). Both the distribution and the numbers of cases have increased. (Figure source: adapted from CDC 2015)

In extreme heat, the air-conditioned built environment is where the city takes shelter, but our built environment also faces impacts from heat. Though the exact impacts of increased temperatures and increasing frequency, duration, and intensity of heat waves on energy use in Boston are not quantified in this report, higher average temperatures will increase energy use in all building categories. Air conditioning is energy intensive; if the city's energy infrastructure does not keep pace with increasing demand (especially a more sudden spike in energy use as a result of a heat wave), then brownouts or blackouts are probable. Furthermore, this increased energy usage can strain the individual building infrastructure of some of Boston's aging building stock that may not have adequate electrical capacity for sufficient cooling.

Studies suggest that climate change alone (absent changes in pollution-precursor emissions) could lead to higher concentrations of air pollution in the northeastern United States, especially for ozone, leading to increasing health risks. Holding emissions constant, climate changes could worsen air quality, and health, by up to 5 percent by mid-century.[57] **By reducing emissions from fossil fuel combustion, we can achieve benefits both for health and for climate.**

Changes in average temperatures can also impact transmission of vector-borne diseases.

Mosquitoes and the diseases they carry are highly sensitive to weather phenomena such as temperature, rainfall, and humidity. For example, rain provides still water for mosquitoes to breed, while drought conditions decrease survival; rising temperatures can enhance the rates of larval development, adult feeding behavior, and pathogen development within the mosquito. Climate change and associated warmer, wetter conditions may increase the risk of vector-borne disease infection, including Lyme disease. Of particular concern are potential future impacts related to the diseases carried by the mosquito *Aedes albopictus*, which is present in the northeastern United States but has not thrived to date because of the constraining influence of cold winters. This mosquito transmits dengue fever and chikungunya and may also carry Zika virus.

INFRASTRUCTURE

Boston's transportation infrastructure could be at risk from increased frequency, duration, and intensity of heat waves.

High temperatures can cause steel railroad tracks to expand. The expansion causes stress to ties, ballasts, and rail anchors that keep the tracks fixed to the ground. Under enough force of expansion, tracks will buckle in an impact sometimes called a "sunk kink." More frequent and severe heat waves may require track repairs or speed restrictions to avoid derailments. Many rail networks require trains to reduce their speed in temperatures over 90 degrees. **With more annual days over 90 expected in the future, the efficiency of the rail system in the city and in the Northeast Corridor could be impacted.**

Thermal expansion can also occur in asphalt and concrete roads in hot temperatures, causing roads to buckle. Road buckling is more common in concrete than in asphalt since it is a less flexible material. Buckling is most common in the early summer months when there is subsurface moisture. Road buckling is difficult to predict and difficult to prepare for aside from cautioning drivers to be aware of the road condition and having repair crews ready. Some bridges and railroad tracks are constructed with expansion joints designed to safely absorb heat-induced expansion of construction materials without any cracking or buckling. Control joints, on the other hand—much less expensive than expansion joints—are strategic cuts in concrete used to allow any cracking from thermal expansion to occur in a controlled fashion for predictability and ease of repair.[58]

Finally, regular road upkeep can be negatively impacted by construction crews' ability to work safely outdoors to maintain roads in the hotter summer months.[59] In Boston, this challenge could be somewhat mitigated by workers being able to work longer into the winter months.

Increased average temperatures will also impact natural systems and green infrastructure in Boston. Natural systems—including the urban tree canopy, public parks and open space, and private and commercial green space—play a significant role in mitigating extreme heat events. These systems can also suffer from chronic stress related to increased average temperatures, drought, and abnormally warm winter seasons.

While tree species near the southern end of their native range and those which are intolerant of urban conditions will be particularly stressed, increased temperatures, mild winters, and dramatic temperature fluctuations may disrupt the seasonal cycles of many species. This would potentially lead to damage or death. These stressors can also leave urban forests particularly vulnerable to pest and pathogens that more freely proliferate with reduced frost depth and increased frost-free days.

Heat-related vulnerabilities to the urban tree canopy and natural systems are a compounding issue. As rising temperatures lead to a potential increase in tree mortality, any loss of canopy coverage or green space will only contribute to the urban heat island effect, reduced air quality, increased stormwater runoff, and decreased quality of life.

[57] Source: Knowlton, Kim et al. "Assessing Ozone-Related Health Impacts under a Changing Climate." Environmental Health Perspectives 112 (15): 1557–1563. 2004. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1247621/.

[58] Source: "The Potential Impacts of Climate Change on U.S. Transportation." Transportation Research Board Special Report 290. National Research Council (NRC). 2008.

[59] Source: "Workers at Risk from Excessive Heat." Occupational Safety and Health Administration. United States Department of Labor.

LAND AREA EXPOSED TO FREQUENT STORMWATER FLOODING UNDER VARYING CLIMATE CONDITIONS

NEIGHBORHOOD	TOTAL AREA ACRES	NEIGHBORHOOD ACRES FLOODED: 2030S–2050S	2050S–2100S	2070S OR LATER
West Roxbury	3,350	240	240	260
Allston/Brighton	2,940	200	200	220
Dorchester	3,780	330	360	410
East Boston	3,430	180	210	260
Jamaica Plain	2,260	170	180	190
Hyde Park	3,260	170	170	180
Roslindale	2,250	170	170	180
Roxbury	2,770	170	170	180
Mattapan	1,560	130	130	140
South Boston	1,940	120	150	190
South End	640	70	90	160
Charlestown	870	60	60	70
Fenway/Kenmore	620	50	50	60
Downtown	770	40	40	50
Back Bay/Beacon Hill	460	30	30	30
Harbor Islands	820	90	100	120
Boston Total	31,720	2,200	2,350	2,720

NEIGHBORHOOD	PERCENT OF NEIGHBORHOOD FLOODED: 2030S–2050S	2050S–2100S	2070S OR LATER
West Roxbury	7%	7%	8%
Allston/Brighton	7%	7%	8%
Dorchester	9%	10%	11%
East Boston	5%	6%	8%
Jamaica Plain	8%	8%	9%
Hyde Park	5%	5%	6%
Roslindale	7%	7%	8%
Roxbury	6%	6%	7%
Mattapan	8%	8%	9%
South Boston	6%	8%	10%
South End	11%	14%	26%
Charlestown	7%	7%	8%
Fenway/Kenmore	8%	8%	9%
Downtown	5%	6%	7%
Back Bay/Beacon Hill	6%	6%	7%
Harbor Islands	11%	12%	15%
Boston Total	7%	7%	9%

All figures presented based on current available land. Any change to the landscape from present conditions, such as subsidence or land loss as a result of sea level rise, are not taken into consideration.

Top Affected by Percentage in the Near Term

Top Three Affected by Acres in the Near Term

The Wastewater Facilities Study completed by BWSC has greatly improved understanding of stormwater flood risk in Boston.

Data and insight provided by BWSC has been instrumental in the completion of the Vulnerability Assessment and the development of the resilience initiatives. As discussed in the Process Overview above, the BWSC's analysis of current and future flooding for 10-year, 24-hour rainfall events has provided a foundation for this Vulnerability Assessment. Though the BWSC stormwater flooding exposure data are not specific enough to approximate structural damage or other direct consequences, the data provide ample details to assess areas impacted by frequent (10-year, 24-hour) and nuisance flooding. Additionally, BWSC has been an active partner through the Climate Ready Boston process, providing insights necessary to develop impactful resilience initiatives.

STORMWATER FLOODING

Without improvements, the existing stormwater system will not be capable of conveying a 10-year, 24-hour rainfall event, causing untreated stormwater runoff to pond in the streets. Further, the system currently struggles to convey the current 10-year, 24-hour rainfall event.

By mid-century, 7 percent of the total land area in the city could be exposed to stormwater flooding for the 10-year, 24-hour event, with that percentage increasing to 9 percent by the end of the century.[60] West Roxbury, Allston, Brighton, East Boston, and South Dorchester have the largest areas of land expected to be affected by stormwater flooding, while the South End and South Boston can expect to see the greatest increase in land area exposed to stormwater flooding as sea levels rise and precipitation events become more extreme. Sea level rise exacerbates stormwater flooding issues by preventing outflow or even causing backflow, resulting in backup of water attempting to flow toward lower ground.

Every neighborhood in Boston will be exposed to frequent stormwater flooding.

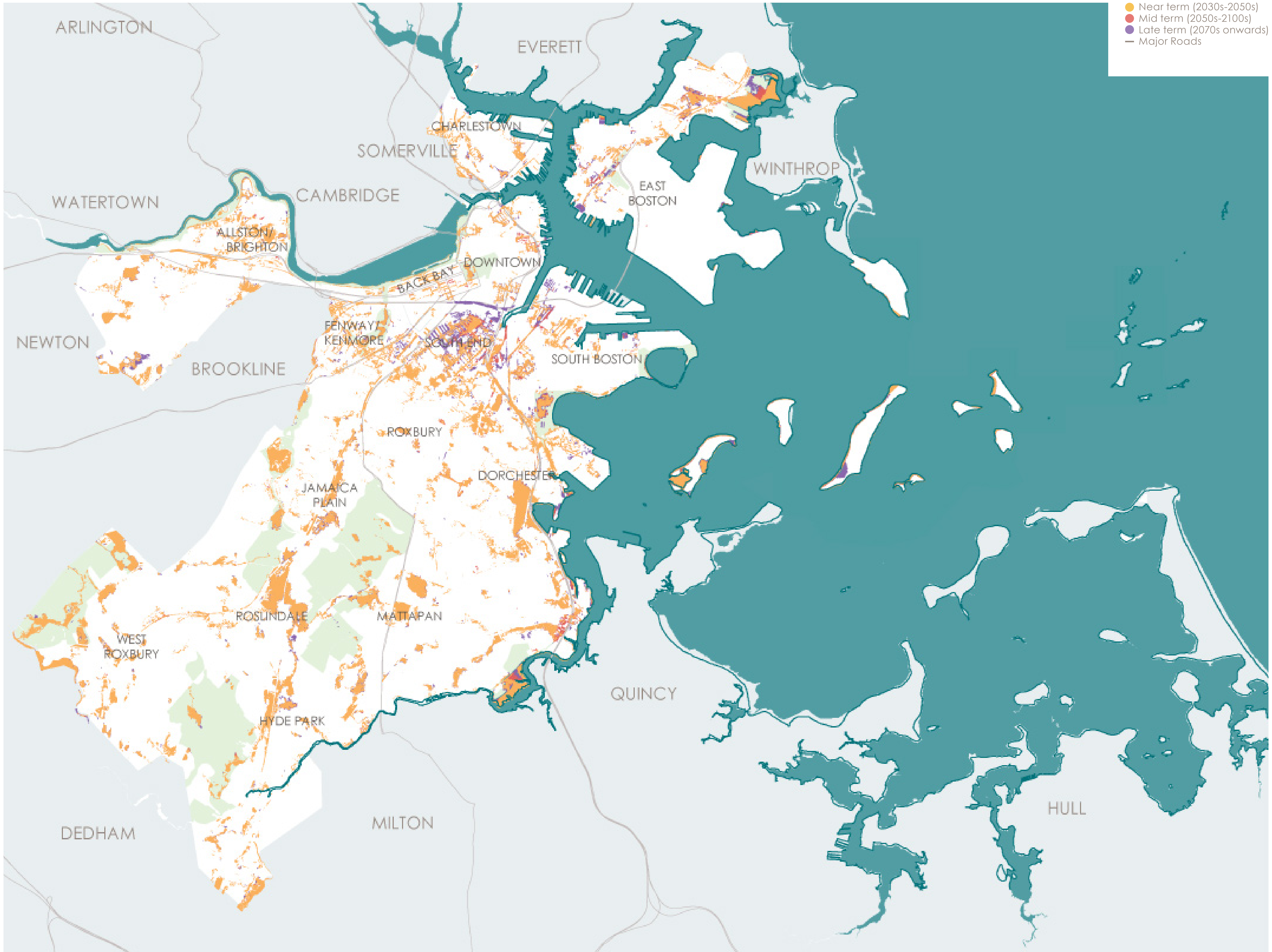
Throughout every neighborhood in the city, there are multiple areas at risk of stormwater flooding for the 10-year, 24-hour design storm, ranging in size from hundreds of square feet along streets to multiple city blocks. The largest areas of stormwater flooding generally are concentrated at low points and in areas with poor hydraulic conveyance or insufficient storage capacity. Key areas include along the coast, where outfalls may be unable to discharge (sea level rise will exacerbate such conditions), transportation corridors with impervious surfaces where water cannot percolate, and designed drainage areas that may be overwhelmed. In total, these flooded areas impact large portions of neighborhoods; **5 percent or more of the land area in each of Boston's 17 neighborhoods will be exposed to flooding from a 10-year, 24-hour storm as early as the 2030s.**

Direct exposure to stormwater flooding increases steadily over time due to climate change.

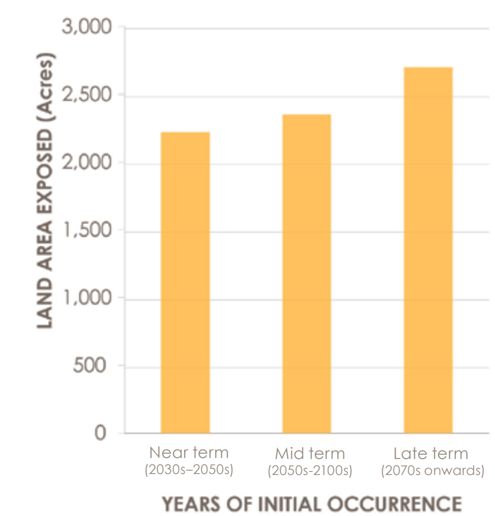
This trend is expected for frequent hazards like the 10-year, 24-hour storm and may not be consistent for other, more severe events. When planning ways to address stormwater flooding, the long-term rate of expected change in stormwater flooding (including potential planned system upgrades) is important for implementation timing.

[60] Land areas are based on the three 10-year, 24-hour stormwater flood extents developed by BWSC and outlined in the Process Overview section. Sea level rise is accounted for in future climate conditions.

FLOODING FROM 10-YEAR, 24-HOUR STORM WITH VARYING CLIMATE CONDITIONS



LAND AREA EXPOSED TO CHRONIC STORMWATER FLOODING



Future frequent stormwater flooding will require gray and green infrastructure investments.

Even with some improvements to the existing stormwater system, untreated runoff is expected to pond. According to the BWSC Wastewater Facilities Study, adding storage to the conveyance systems, making major upgrades in individual pump station capacities, or combinations of these alternatives will improve hydraulics but may not be able to mitigate stormwater flooding in the future caused by climate change. Further analyses are necessary to examine the projected severity of ponding for future climate projections after improvements are made to the stormwater system.

PEOPLE

Over 85,000 people[61] currently live in areas expected to be directly exposed to frequent stormwater flooding by the end of the century.

Of the existing structures exposed to expected stormwater flooding, 80 percent are either residential or mixed-use buildings, impacting tens of thousands of residents and workers in the exposed buildings and many more that use nearby streets and open spaces that would be flooded.

Stormwater flooding can lower indoor air quality and worsen asthma symptoms.

Because people spend at least 90 percent of their time indoors, the quality of the air indoors heavily affects health status. Moisture and air humidity as well as the dampness of building materials can significantly impact indoor air quality.

Any residential or commercial structures that experience flooding will face potential long-term challenges related to mold growth and resulting respiratory problems. This risk is exacerbated in buildings that are adjacent to poorly drained soils, have poorly sealed exterior windows and roofs, or use forced hot air, which can become a conveyor of air from damp basement areas.

Some socially vulnerable populations may face significant challenges with nuisance flooding.

The presence of residential buildings in flooded areas likely translates to nuisance flooding, which rarely damages property but impacts road access and mobility. Nuisance flooding affects quality of life for people in general, with a higher probability of impacting socially vulnerable populations. Flooded sidewalks, for example, can especially impact someone in a wheelchair or someone who has difficulty walking, making it more difficult to get to a bus stop, to work, to a shop for groceries, or to a healthcare appointment. Flooded roads and sidewalks also disrupt neighborhood connectivity and isolate residents from one another, contributing to social isolation. For populations burdened with significant stresses and fewer resource redundancies, this hazard will cause disproportionate impacts.

BUILDINGS

Without stormwater system improvements, over 11,000 structures citywide[62] will be directly exposed to late-century stormwater flooding as a result of sea level rise and increased precipitation. Many more will be indirectly impacted.

Though stormwater flooding exposure is primarily a nuisance and largely does not imply structural damage even with direct exposure, ponding water may compromise access to buildings, present transportation challenges, and damage yards and other landscaped areas. In addition, buildings that are still connected to the combined sewer system may experience wastewater backup issues.

[61] Current population residing in areas expected to be exposed. The population has not been projected into the future.

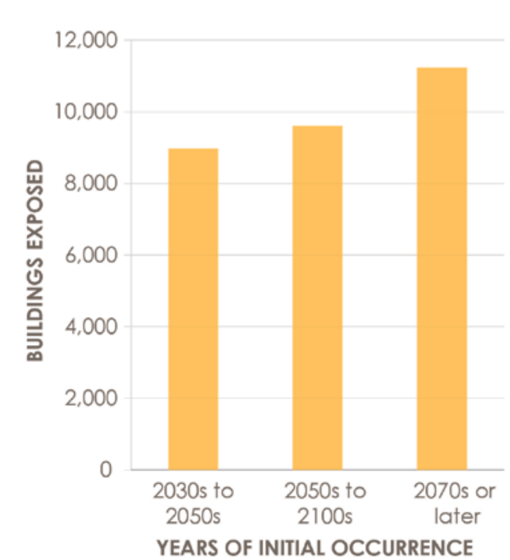
[62] Current building stock in areas expected to be exposed. The change in building stock has not been projected.

Although not evaluated within this Vulnerability Assessment, rain events more extreme than the 10-year, 24-hour rainfall will have more severe impacts in Boston, though the impacts would be less frequent. Additional analysis on extreme event flooding and the sensitivity to climate change is recommended for future analyses.

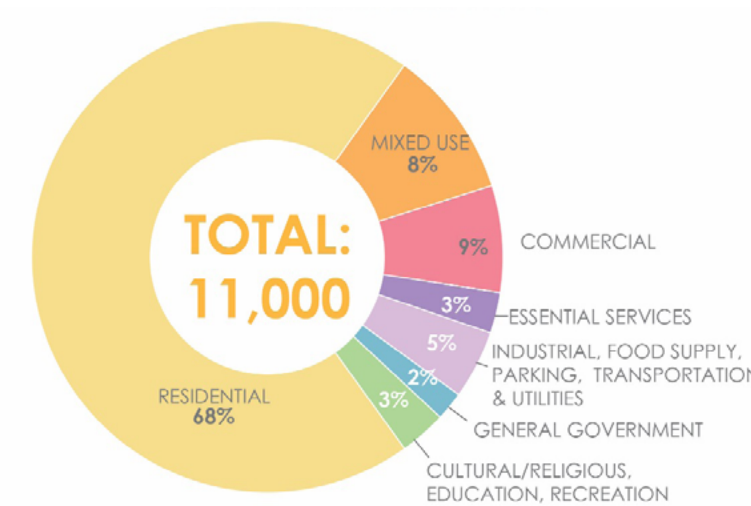
BUILDINGS EXPOSED TO FREQUENT STORMWATER FLOODING WITH VARYING CLIMATE CONDITIONS

NEIGHBORHOOD	2030S–2050S	2060S–2090S	2070S–2100S
Dorchester	1,200	1,260	1,390
South End	1,110	1,320	2,040
Roslindale	880	890	960
Roxbury	870	900	950
East Boston	670	820	1,000
Allston/Brighton	660	660	730
Mattapan	640	670	710
Back Bay/Beacon Hill	530	580	600
Fenway/Kenmore	440	460	490
West Roxbury	420	420	450
Hyde Park	410	420	460
Jamaica Plain	340	350	390
South Boston	340	370	490
Downtown	260	310	350
Charlestown	200	210	240
Harbor Islands	<10	<10	<10
Boston Total	**8,970**	**9,610**	**11,230**

BUILDINGS EXPOSED TO CHRONIC STORMWATER FLOODING



BUILDINGS EXPOSED TO FREQUENT STORMWATER FLOODING BY TYPE
(2070s TO 2100s)



INFRASTRUCTURE

Access and mobility can be impacted at multiple scales ranging from building entrances to local streets to major thoroughfares like highways and MBTA lines.

Without improvements to the stormwater management system, frequent stormwater flooding is projected near major thoroughfares, such as Columbus Avenue, Tremont Street, and Morrissey Boulevard, as well as Interstates 90 and 93 and along the MBTA Orange and Red Lines. Because data resolution is not great enough, this analysis may not be well suited to accurately reflect stormwater flooding extents along these MBTA lines, roadways, and highways. Nevertheless, it is clear that, at a minimum, the flood data highlight potential nuisance flooding at intersections and onramps providing access to these transportation routes. Many of these transportation routes are also designated evacuation routes, which may become increasingly more flood prone to heavy rainfall.

Increased precipitation may impact emergency response time throughout the city.

Several hospital campuses, fire stations, and police stations are expected to experience frequent stormwater flooding in their vicinity and possibly within structures in the future, including Carney Hospital, Massachusetts General Hospital, Boston Children's Hospital, Boston Medical Center, and the Boston Police Headquarters. Impeded vehicle access to and from such facilities may impact the timeliness of response vehicles to emergency situations. Access issues due to stormwater flooding may also impact shift changes—essential services operate around the clock, and a delay in shift change could potentially result in a diminished quality of service due to tired employees. Every minute counts with essential services, and extended service time is associated with increased risk of mortality and harm in health and safety situations.

ECONOMY

Frequent stormwater flooding will inconvenience customers and discourage them from using nearby businesses.

Though this analysis does not have sufficient data to quantify economic impacts, it is expected that local business may be negatively impacted by frequent stormwater flooding. Around 800 commercial buildings are expected to be within late-century frequently flooded areas, with greatest concentrations of exposed commercial buildings located in Downtown and Dorchester. Businesses can expect brief closures during and after flood events, with the potential for prolonged closure if there is direct damage to property. Even without damages to buildings, continued flood damage to parking lots, sidewalks, and landscaping can cause these assets to deteriorate more rapidly, potentially contributing to uneven surfaces and negative appearances that would impact safety, as well as customer choices.

COASTAL AND RIVERINE FLOODING

The probability of high-impact storms in the City of Boston is increasing over time.

Coastal and riverine flooding is expected to lead to the most significant increases in climate hazard consequences to people, buildings, infrastructure, and the economy.

Over the course of the twenty-first century, Boston will become incrementally more exposed to extensive coastal and riverine flooding in neighborhoods fronting Boston Harbor, Fort Point Channel, Dorchester Bay, and the Chelsea, Mystic, and Charles Rivers. Neighborhoods fronting the coastline, like Downtown, East Boston, and South Boston, are especially vulnerable currently and will grow more vulnerable in the coming decades.

Coastal and riverine flooding consequences will increase dramatically by the middle and end of the century as storm frequency increases and flooding via new pathways becomes more probable.

Many areas impacted by lower probability events (i.e., 1 percent annual chance floods) in the early to mid-century are expected to face exposure to flooding from the monthly highest tides by the mid- to late century. As sea levels rise in Boston Harbor, coastal flooding is also significantly more likely to penetrate inland through Fort Point Channel to much of the South End and the northern portion of Roxbury. Additionally, neighborhoods along the Charles River, including Allston/Brighton, Back Bay/Beacon Hill, and Fenway/Kenmore, are more likely to face exposure to flooding late in the century when the Charles River Dam is at a higher risk of being flanked or overtopped.

Flood hazard data and adaptation recommendations developed as part of the 2015 MassDOT-FHWA study are an essential component of the Climate Ready Boston analysis.

As discussed in this section and the Focus Areas chapter, the rich MassDOT-FHWA flood hazard dataset has been critical to quantifying exposure and consequences. Coupled with the Climate Ready Boston general building stock and asset inventory, a comprehensive assessment of coastal and riverine flooding exposure and consequences is possible within Climate Ready Boston, while creating a foundation for future studies.

The factors driving risk from coastal and riverine flooding vary greatly along the waterfront.

Boston could manage much of the coastal flooding projected early in this century by addressing low points at the waterfront through which water could penetrate inland. This kind of approach could be particularly effective in Charlestown and East Boston, where the length of waterfront sections with low elevations is comparatively limited. South Boston, in contrast, will be challenged early in the century even with relatively moderate increases in sea levels. In this neighborhood, significant portions of the waterfront serve as flood entry points, so developing strategies to increase protection would require more significant investments in infrastructure or more complex coastal flood resiliency planning. Other flood entry points, such as the flanking of the Charles River Dam or Fort Point Channel, are likely to require large-scale infrastructure improvements to reduce flood risk but would likewise result in significant benefits, reducing flood exposure across multiple neighborhoods. See the Protected Shores resilience initiatives (p.98) and the Focus Areas chapter (p. 148) for more details on potential flood protection systems.

As the sea level continues to rise, the likelihood of major floods will increase from a 1% annual chance to a monthly reality

A **1% annual chance** flood ≈ A **10% annual chance** flood ≈ Monthly flooding

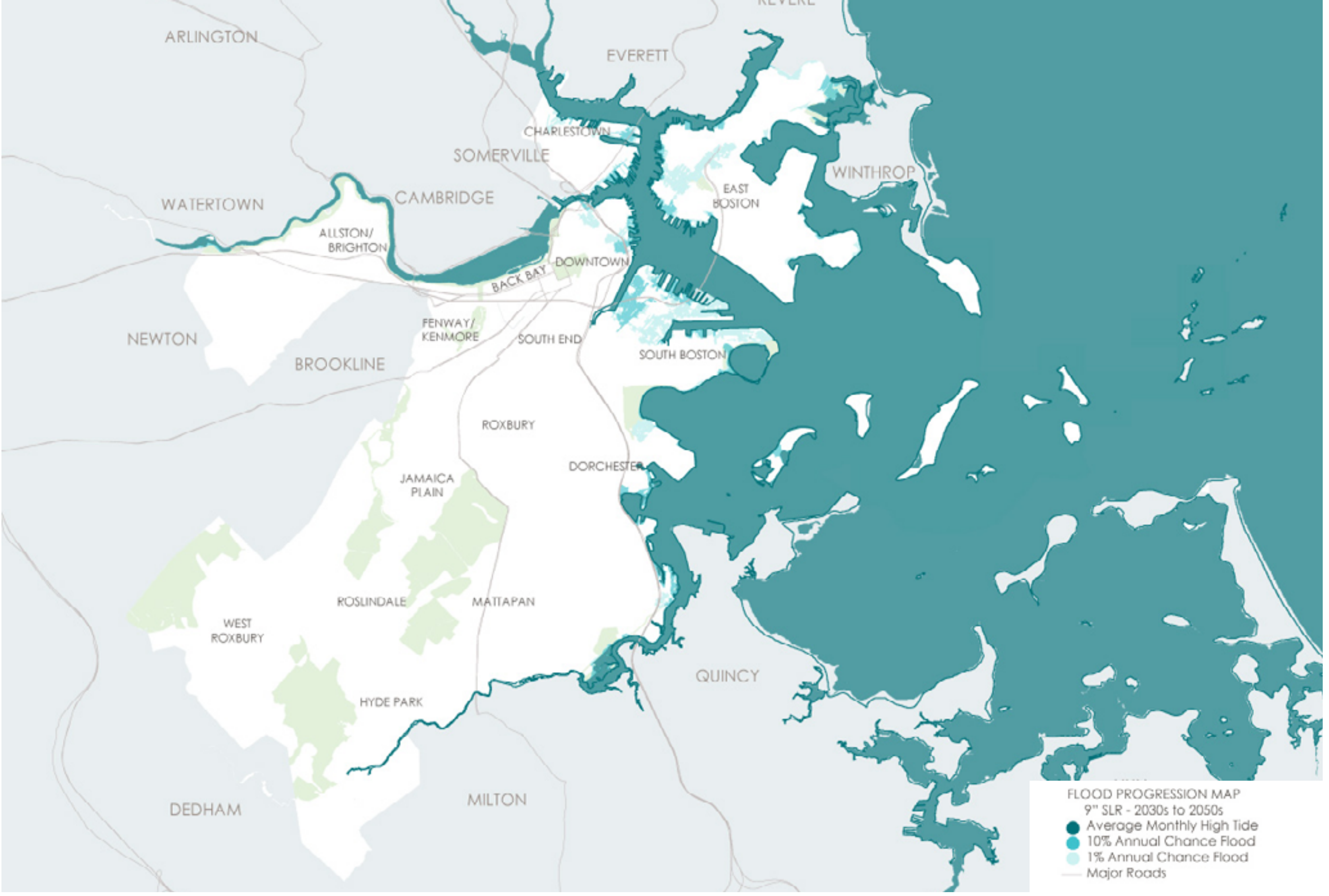
2030s - 2050s | **2050s - 2100s** | **2070s or later**

COASTAL AND RIVERINE FLOOD SCENARIOS

For each of the three sea level rise scenarios considered, Climate Ready Boston also evaluated expected exposure and impacts for four modeled flood events, as well as the average monthly high tide (see Process Overview for more on the average monthly high tide). The modeled flood events coincide with the 10 percent, 2 percent, 1 percent, and 0.1 percent annual chance flood events, plus appropriate sea level rise. The lower probability the event, the higher the magnitude and severity of impact can be expected from the storm when it arrives.

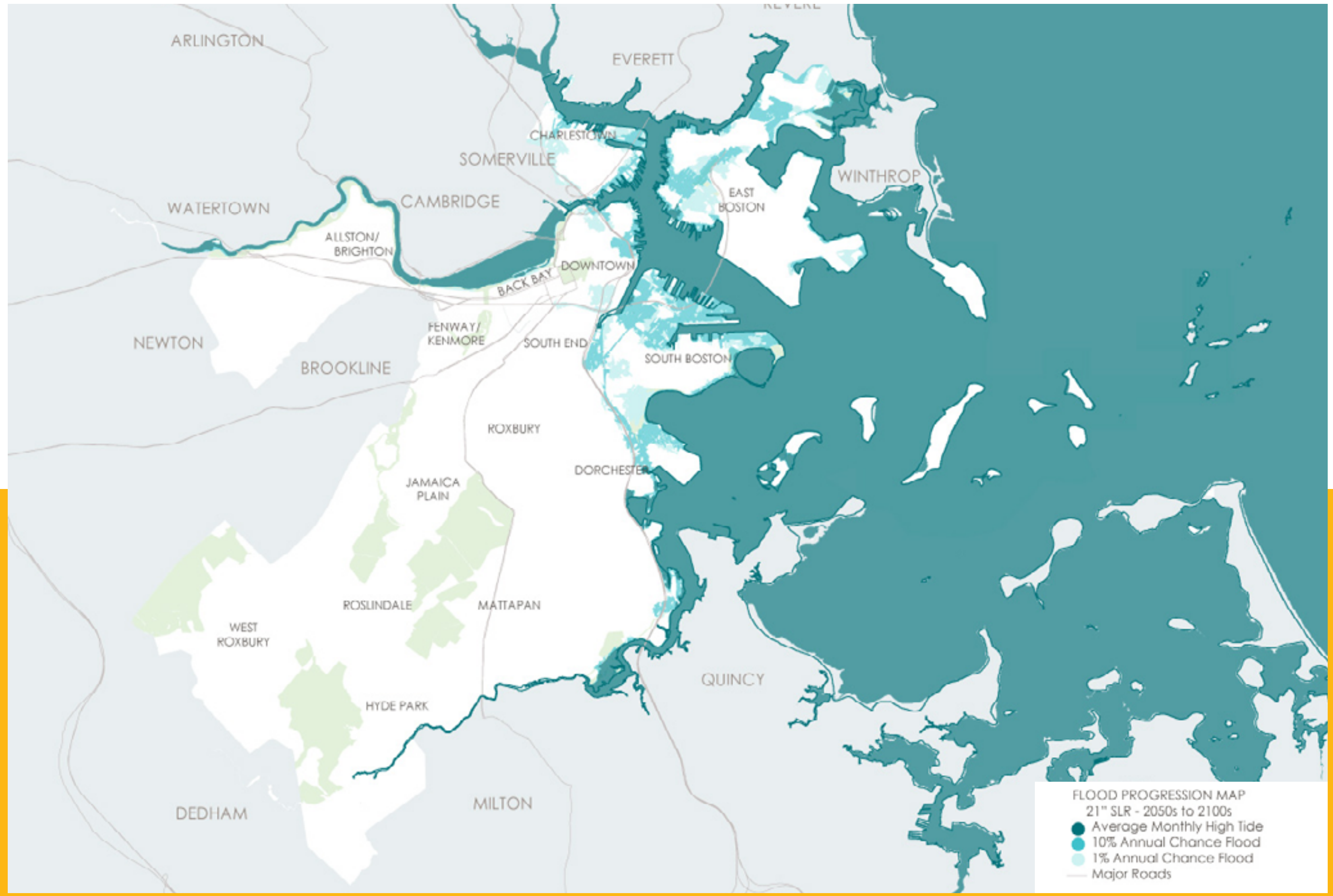
PERCENT ANNUAL CHANCE

The 1 percent annual chance flood has a 1 in 100 chance of being equaled or exceeded in any given year and is the primary coastal flood hazard delineated in FEMA FIRMs. Percent annual chance flood elevations do not imply a period of time between occurrences. Though the chance of occurrence each year may seem relatively low, a 1 percent annual chance event could occur multiple times in a given year, decade, or century. Climate Ready Boston uses a 1 percent annual chance flood nomenclature rather than the "100-year" flood, in order to limit confusion related to the possible time horizon of an event occurring. The 100-year flood event terminology can more easily be misinterpreted to imply that 100-year events occur only once every 100 years. In reality, these events have close to a one in three chance of occurring at least once during a 30-year period.

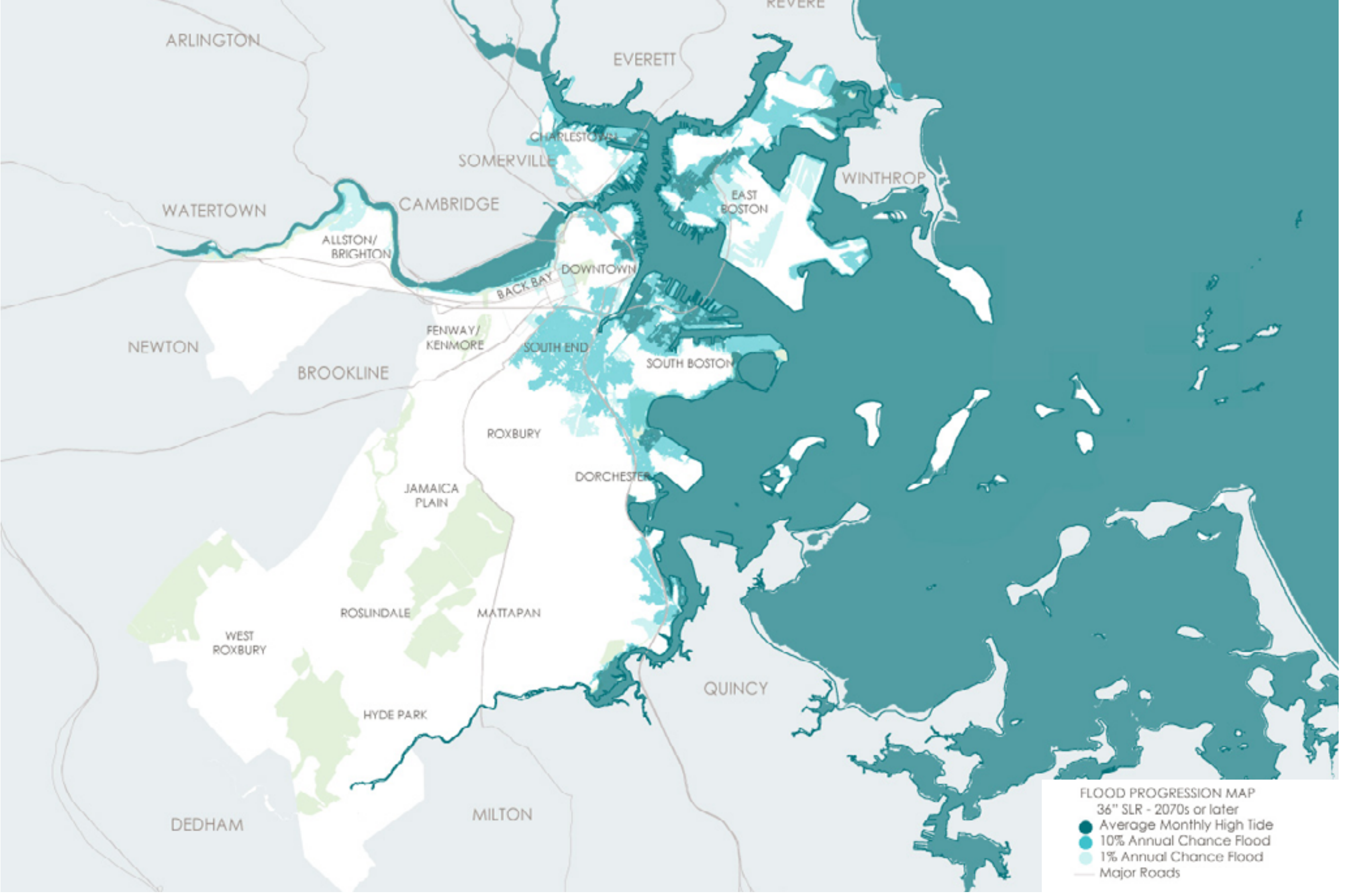


2030s–2050s: 9 INCHES OF SEA LEVEL RISE[63]

[63] Future flood extents shown only within City of Boston for all conditions.



2050s-2100s: 21 INCHES OF SEA LEVEL RISE



2070s OR LATER: 36 INCHES OF SEA LEVEL RISE

AREA AND PERCENT OF NEIGHBORHOOD EXPECTED TO EXPERIENCE FLOOD IMPACTS
UNDER THE 1 PERCENT ANNUAL CHANCE FLOOD EVENT IN EACH SEA LEVEL RISE SCENARIO

		LAND AREA EXPOSED (ACRES)				PERCENT OF NEIGHBORHOOD EXPOSED			
Neighborhoods	Total Land Area (Acres)	9" SLR 1% annual chance	21" SLR 1% annual chance	36" SLR 1% annual chance	36" SLR AMHT	9" SLR 1% annual chance	21" SLR 1% annual chance	36" SLR 1% annual chance	36" SLR AMHT
I. Greatest Exposure & increasing throughout century									
Charlestown	870	120	310	460	110	14%	36%	54%	12%
Downtown	770	110	240	350	70	14%	31%	45%	10%
East Boston	3,340	540	1,040	1,680	480	16%	30%	49%	14%
Harbor Islands	820	200	230	260	200	25%	28%	32%	24%
South Boston	1,940	470	930	1,220	360	24%	48%	63%	19%
II. Lower Exposure today, but significant jump late century									
Allston / Brighton	2,940	30	70	240	20	1%	2%	7%	1%
Back Bay / Beacon Hill	460	<10	<10	80	<10	<1%	1%	17%	<1%
Roxbury	2,770	<10	<10	130	<10	<1%	<1%	5%	<1%
Dorchester	3,780	240	430	750	220	6%	11%	20%	6%
South End	640	<10	20	450	<10	<1%	3%	71%	<1%
III. Other Neighborhoods									
Fenway / Kenmore	620	<10	<10	<10	<10	<1%	<1%	<1%	<1%
Hyde Park	3,260	0	0	0	0	0	0	0	0
Jamaica Plain	2,260	0	0	0	0	0	0	0	0
Mattapan	1,560	0	0	0	0	0	0	0	0
Roslindale	2,250	0	0	0	0	0	0	0	0
West Roxbury	3,350	0	0	0	0	0	0	0	0
Boston Total	**31,720**	**1,720**	**3,280**	**5,630**	**1,470**	**8%**	**10%**	**18%**	**8%**

AMHT is the Average monthly highest tide

Ten percent of Boston's land area is expected face exposure to 1 percent annual chance coastal and riverine flooding as soon as the 2050s. In the late century, this increases to 18 percent.

As soon as the 2070s, almost 5 percent of Boston's land area is expected to face exposure to inundation from the average monthly high tide.

East Boston and South Boston have the most land area affected by coastal flooding and sea level rise.

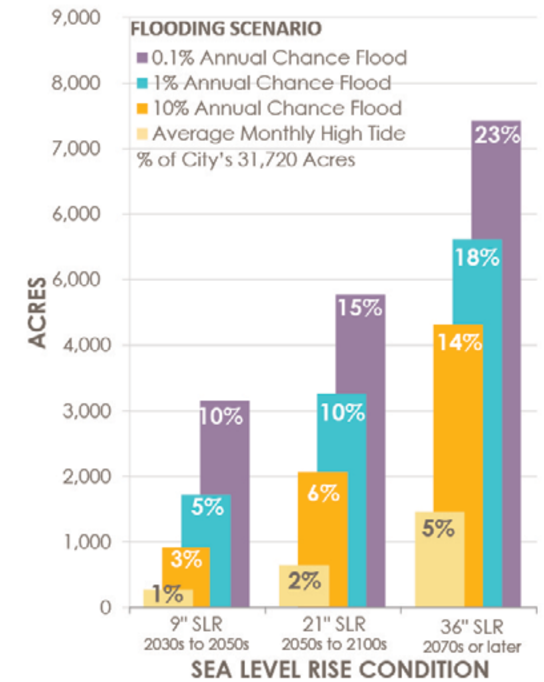
BACK TO THE FUTURE?

Landmarks nearest the coast, like the Institute for Contemporary Art, the New England Aquarium, and Boston Children's Museum, lie in some of the most exposed parts of the city. Faneuil Hall and Quincy Market are slightly farther inland but without additional actions are also at risk of flooding during future high tides. Many of the city's oldest landmarks, such as the Old State House, Paul Revere House, and Old North Church, sit on higher ground, above flood risk. Why are many of the Boston's oldest landmarks out of the projected floodplains?

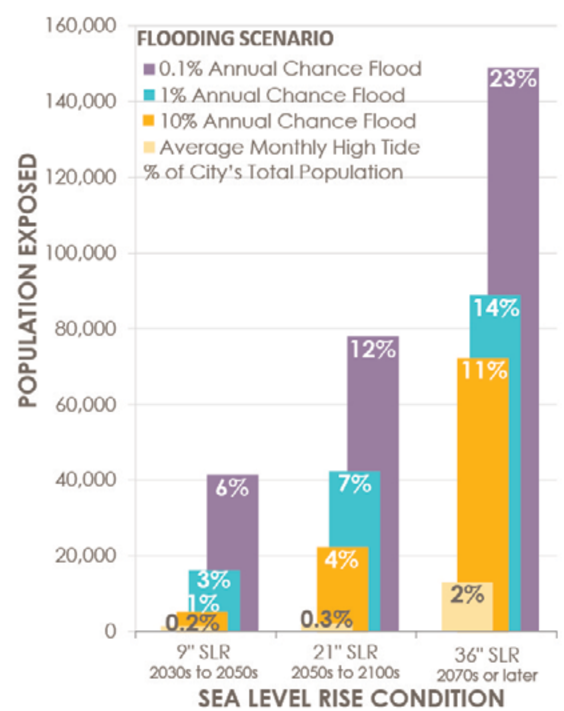
The relative safety of these older landmarks reflects the history of our city: transformed through centuries of landfill, the original islands and peninsula of the city remain higher and more protected than areas built on filled tidelands. Comparison of Boston's original landforms to the 1 percent annual chance floodplain late in the century shows a close parallel; large portions of the original landforms in Charlestown, the North End, Downtown, East Boston, and South Boston remain out of the coastal floodplain even late in the century while areas that were filled over time are at higher risk of flooding from coastal storms. However, some filled areas, like parts of Columbia Point, were filled to higher elevations and therefore face less exposure to future flooding.

The impacts of climate change are not only isolated to coastal storms. By late in the century, the most noticeable changes to our current landscape will likely be seen during high tides, which will creep higher and higher over the decades. By 2100, the extent of future high tide could be similar to flooding caused by a major storm early in this century.

CITYWIDE LAND ACRES EXPOSED



CITYWIDE POPULATION EXPOSED



PEOPLE

In the late century, 75 percent of buildings exposed will be either residential or mixed-use, potentially exposing over 88,000 people (nearly 15 percent of Boston's population) to coastal and riverine flooding.[64]

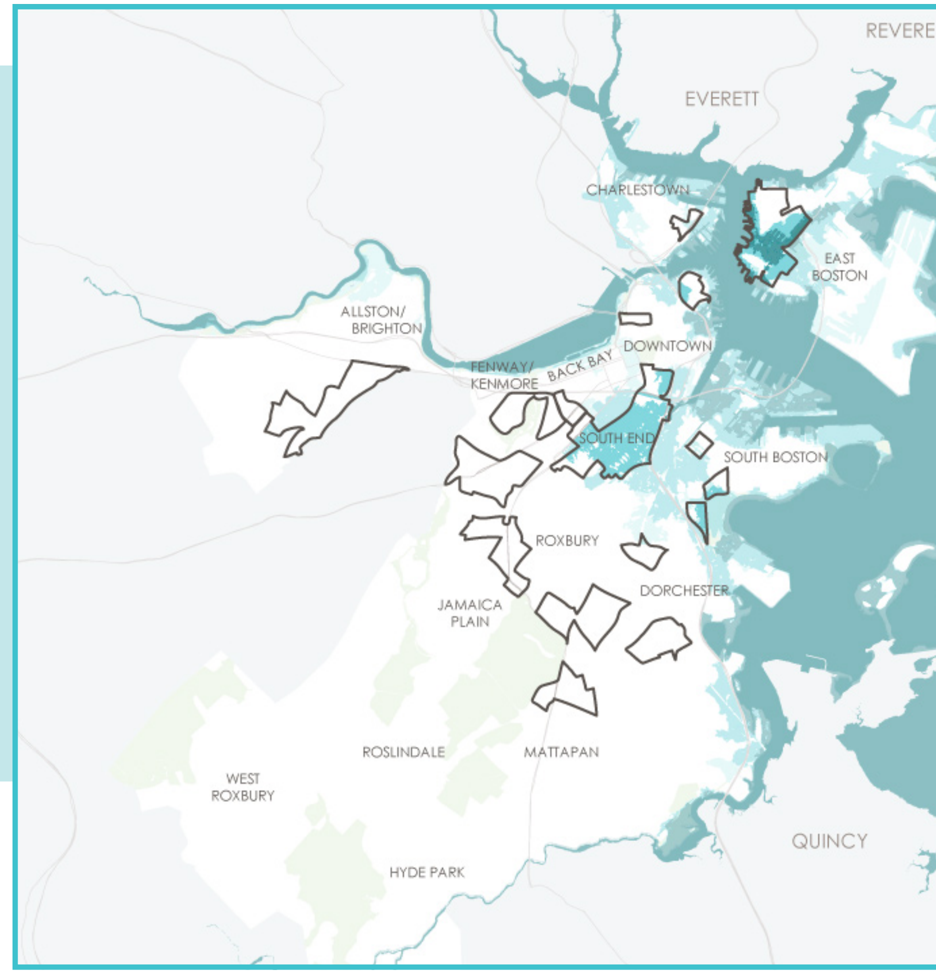
The majority of the more than 88,000 Bostonians who will be exposed to late-century 1 percent annual chance coastal storms and sea level rise impacts reside in four neighborhoods: Downtown, East Boston, South Boston, and the South End. Projected future 10-year, 24-hour stormwater flooding for the same time period has similar building and population exposure statistics. Nevertheless, coastal and riverine flooding is considered more dangerous, as it is more likely to result in massive property damage and injury and can require years for full recovery. Further, unresolved impacts following coastal storms can become long-term chronic issues.

For late-century climate conditions, estimates show that more than 9,000 people in these four neighborhoods will be in need of public shelter due to a coastal flood. The existing emergency shelters located in these neighborhoods have a combined capacity of just over 1,000 people.

[64] All population, structure, and infrastructure exposure figures refer to potential future hazards projected onto current conditions. No projections have been completed for the purposes of the quantitative analysis due to inherent uncertainty.

POPULATION EXPOSED BY SEA LEVEL RISE CONDITION

		9" SLR (2030s - 2050s)				21" SLR (2050s - 2100s)				36" SLR (2070s or later)			
Neighborhood	**Total**	**AMHT**	**10%**	**1%**	**0.10%**	**AMHT**	**10%**	**1%**	**0.10%**	**AMHT**	**10%**	**1%**	**0.10%**
East Boston	40,500	280	820	7,020	16,670	770	9,090	16,700	18,500	6,300	18,180	19,070	20,410
Downtown	30,020	630	2,190	4,680	9,600	860	3,770	9,940	12,810	2,990	11,120	13,950	16,090
South Boston	31,780	100	1,680	2,330	6,400	100	3,090	7,340	9,210	2,270	8,750	10,960	12,260
Dorchester	87,380	0	150	340	5,740	20	3,530	5,100	6,590	160	5,760	6,820	9,700
Charlestown	16,430	350	420	1,340	3,600	350	2,530	3,730	4,750	1220	3,920	5,180	5,540
South End	38,600	0	0	0	230	0	0	240	23,350	0	24,980	27,400	35,940
Back Bay/Beacon Hill	22,600	0	0	0	0	0	0	0	1,920	0	10	4,630	13,650
Roxbury	71,580	0	0	0	0	0	0	0	720	0	1060	1,830	3,590
Allston/Brighton	74,990	0	0	0	0	0	0	0	190	0	0	190	2,380
Fenway/Kenmore	44,260	0	0	0	0	0	0	0	0	0	0	60	31,400
Harbor Islands	0	0	0	0	0	0	0	0	0	0	0	0	0
Hyde Park	32,310	0	0	0	0	0	0	0	0	0	0	0	0
Jamaica Plain	42,070	0	0	0	0	0	0	0	0	0	0	0	0
Mattapan	33,680	0	0	0	0	0	0	0	0	0	0	0	0
West Roxbury	30,440	0	0	0	0	0	0	0	0	0	0	0	0
Roslindale	37,720	0	0	0	0	0	0	0		0	0	0	0
Boston Total	**634,440**	**1,360**	**5,260**	**15,700**	**42,250**	**2,110**	**22,010**	**43,060**	**78,055**	**12,930**	**73,790**	**90,080**	**150,950**



The South End and East Boston both have significant populations of low- to no-income residents within future flood extents.[67]

Areas outlined on the map in black represent census tracts with the top quartile of concentrations of low- to no-income residents. Census tracts falling in the top quartile had concentrations of over 170 low-income households per acre of land area.

A major storm at 36 inches of sea level rise impacts the vulnerable neighborhoods of East Boston, Dorchester, Roxbury, and the South End.

The South End and East Boston both have significant populations of low- to no-income residents within future flood extents.

LOW-TO-NO INCOME 36" SLR FLOODING RISK
Low-to-No Income Top Quartile
Average Monthly High Tide
10% Annual Chance Flood
1% Annual Chance Flood
Based on density per census tract

At the 36-inch sea level rise condition, 10 percent of Boston's K–12 schools are exposed to lower-probability flood impacts.[65]

Closure of these schools as a result of flooded access or direct damage would affect over 11,500 current students—15 percent of all of Boston's school-age population.

Coastal flooding is particularly disruptive and dangerous for those living in chronically stressed neighborhoods, without resources or education for disaster preparedness and recovery.

Coastal flooding will have a significant near-term impact on socially vulnerable populations living in waterfront areas like East Boston. Moreover, with 36 inches of sea level rise, a major coastal storm will impact even inland neighborhoods like Roxbury and portions of Dorchester. This is a concern because of the multiple layers of vulnerability that these neighborhoods are already facing.

The risk of major storms is very difficult for members of the population to conceptualize if they have not experienced one in their lifetime. As such, risk may be underappreciated, and residents may fail to prepare adequately or evacuate on time. In communities with lower levels of education and income, people may simply lack the resources to adequately prepare. Additionally, large-scale flood defense infrastructure can result in a false sense of security for some communities; flood defense systems, like in New Orleans, can never fully eliminate risk of inundation, making multiple mitigating lines of defense, as well as preparedness and evacuation measures, vitally important. Such factors together exacerbated impacts of Hurricane Katrina in Louisiana in 2005.

[65] Percentage of all schools mapped by Climate Ready Boston thus far.

In a major flooding emergency, effective communication of information becomes essential to safety and even survival. Those lacking information because of social isolation or limited technology, literacy, or English proficiency are at risk of missing crucial information, and preparedness plans must take this into consideration. Flooding carries physical risk of bodily harm, even after the immediate storm danger has passed. Within the week following Hurricane Sandy, more than 10 percent of the population in the flooded area suffered some sort of injury; injuries occurred during evacuation and cleanup or repair of damaged or destroyed homes.[66]

Those with impaired mobility (older adults, people with medical illness, and people with disabilities) may need special transportation and are at risk of being left behind. Recovery resources must be accessible to those with mobility or other issues. Evacuation of hospitalized or long-term care patients carries with it additional risks of death or injury.

[66] Source: "Nonfatal Injuries 1 Week after Hurricane Sandy." CDC Report. October 2014. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6342a4.htm.

[67] Map highlights census tracts falling within top quartile for density of low- to no-income residents. Flood extents shown are with 36 inches of sea level rise.

BUILDINGS

By number of structures alone (as opposed to square footage or market value), more than 10 percent of Boston's existing buildings will be exposed to late-century flooding.

Of exposed buildings late century, the majority (almost 80 percent) are concentrated in the four neighborhoods of the South End, East Boston, South Boston, and Downtown, in that order.

Office, retail, and service-based commercial buildings are among the top impacted buildings in terms of numbers for all sea level rise conditions.

After residential and mixed-use buildings, commercial structures make up the highest percentage of structures exposed to sea level rise and coastal storms (20 percent, 12 percent, and 10 percent for the early-, mid-, and late-century sea level rise conditions, respectively). Commercial buildings vulnerable to sea level rise and coastal storms are most concentrated in Downtown and South Boston.

Toward the end of the century, 5 percent of Boston's real estate market value is expected to suffer flood exposure to high tides, increasing to 25 percent for less frequent but more severe events.

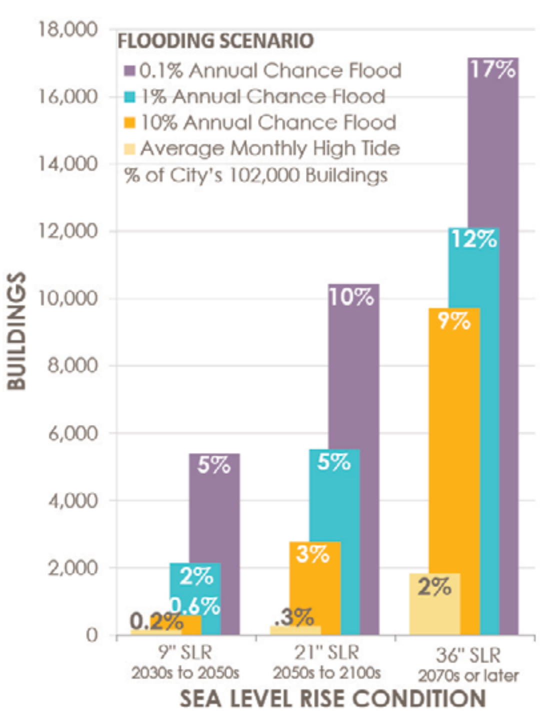
Another way to view buildings' exposure is through real estate market value. Market value exposure takes into consideration the size and relative desirability of location and features of structures exposed to future flood risk, and considers land value. Land value is an important consideration when looking at exposure of buildings to recurrent flooding, particularly flooding of the sort that may occur with high tides. Studies have shown that real estate market values can decrease significantly with increased perception of flood risk. The area identified as the Special Flood Hazard Area on FEMA flood maps is subject to mortgage-related flood insurance requirements, as well as higher flood insurance premiums. As such, flood risk exposure to lower-probability events may not only affect the cost of ownership of exposed buildings in the future but also affect their desirability.

By the end of the century, mixed-use buildings will occupy about half of real estate market value exposure to flooding from high tides alone, followed (by a wide margin) by commercial, general government, and residential uses, in that order. High tide exposure of the market value of transportation-related buildings[68] increases by significant orders of magnitude from mid- to late century. Transportation-related structures and essential facilities (such as Fire, EMS, police stations, and hospitals) are expected to have over $1.3 billion in property value exposed to average monthly high tide flood events during that same period.

Any structure can experience cascading impacts as a result of direct losses to other infrastructure service sectors, regardless of whether the site experiences direct flood impacts. This concept is further described in the Interdependencies section below.

[68] Transportation-related buildings are those defined by the Boston Assessing Department as terminals for trucks, air freight, bus and rail, and the airport, in addition to Port Authority property, piers and docks, hangars, and railroad structures.

CITYWIDE BUILDINGS EXPOSED



BUILDINGS EXPOSED BY SEA LEVEL RISE CONDITION

		9"SLR (2030s - 2050s)				21" SLR (2050s - 2100s)				36" SLR (2070s or later)			
Neighborhood	**Total**	**AMHT**	**10%**	**1%**	**0.10%**	**AMHT**	**10%**	**1%**	**0.10%**	**AMHT**	**10%**	**1%**	**0.10%**
East Boston	6,930	20	90	1,070	2,540	70	1,420	2,570	2,920	990	2,830	3,080	3,330
Downtown	2,960	60	160	390	830	80	390	850	1,150	300	1,050	1,240	1450
South Boston	6,800	20	160	350	730	30	420	1,000	1,360	280	1,270	1,530	1,750
Dorchester	15,740	30	90	170	820	60	360	610	1,090	120	850	1,210	2,000
Charlestown	3,420	20	70	140	410	30	170	420	610	140	470	680	780
South End	3,980	0	0	0	50	0	0	50	2,950	0	3,120	3,440	3,730
Allston/Brighton	22,600	0	0	0	0	0	0	0	1,920	0	10	4,630	13,650
Harbor Islands	130	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Back Bay/ Beacon Hill	3,470	0	0	0	0	0	0	0	200	0	<10	600	1,940
Roxbury	10,000	0	0	0	0	0	0	0	80	0	90	240	460
Fenway/ Kenmore	2,000	0	0	0	0	0	0	0	0	0	0	<10	1,440
Hyde Park	8,490	0	0	0	0	0	0	0	0	0	0	0	0
Jamaica Plain	6,690	0	0	0	0	0	0	0	0	0	0	0	0
Mattapan	6,090	0	0	0	0	0	0	0	0	0	0	0	0
Roslindale	7,660	0	0	0	0	0	0	0	0	0	0	0	0
West Roxbury	9,390	0	0	0	0	0	0	0	0	0	0	0	0
Boston Total	101,980	150	580	2,130	5,380	260	2,750	5,530	10,430	1,830	9,710	1,2100	1,7140

Building exposure is based on present-day building stock currently located within projected flood area.

INFRASTRUCTURE

Key components of Boston's transportation system, most notably MBTA T service and evacuation routes, may be at risk to coastal and riverine flood impacts in the near future.

Many residents depend on Boston's public transit system to get to work, school, or healthcare, and this system is one of the first to face exposure to coastal flooding. Twelve MBTA stations face exposure to sea level rise impacts from lower-probability events in the near term. This includes four Blue Line stations that connect East Boston to Downtown and eight Silver Line stations in South Boston. With increasing sea level rise, almost a third of MBTA T stations face exposure as soon as the 2070s. Any MBTA Blue and Orange Line station closures[69] could restrict travel between East Boston, Downtown, and Charlestown; MBTA Silver Line station closures would affect South Boston and the South End. Service interruptions at one station may impact service for an entire line.

Alternative transportation options may be especially difficult for East Boston and Charlestown residents to take advantage of, as these areas are physically separated from other Boston neighborhoods.

Major roads and evacuation routes, as well as Central Artery/Tunnel (CA/T) facilities, are expected to face significant sea level rise impacts, and bus transit can expect to be interrupted in the case of flooded roadways or tunnels. Even in the near future, one-third of the evacuation routes serving the city are expected to have at least some portion impacted during storm events. As soon as the 2070s, the majority of identified evacuation routes may have some portion flooded during low-probability storms. In addition, two-thirds of the CA/T assets[70] are within identified flood extents of coastal storms by the end of the century. CA/T and major road vulnerability poses potential threats to evacuation processes, and flood repairs to these routes would extend gridlock and traffic-delay issues, affecting air quality and quality of life for commuters. Moreover, for those who do not have access to a personal vehicle or cannot afford a taxi or similar option in the case that alternate forms of transportation are needed, getting around may not be possible.

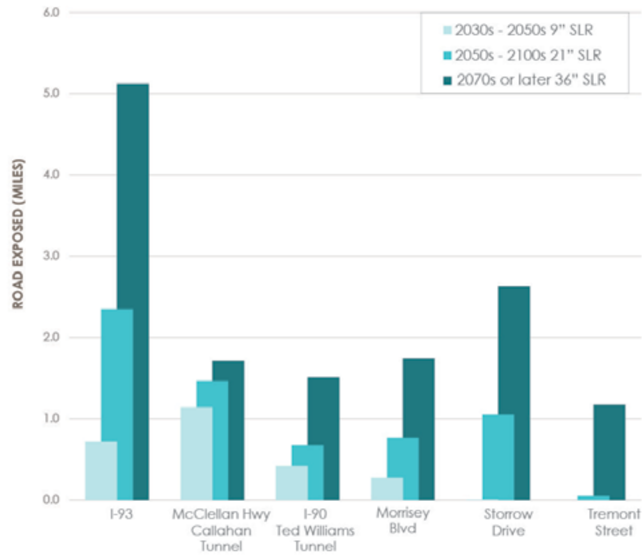
MassDOT is currently working on resilience plans for the Sumner, Callahan, and Ted Williams Tunnels to combat coastal storm and sea level rise impacts expected in the near future. Additional consequences of transportation failures are described in the Interdependencies section below.

Two hundred and forty essential and public facilities currently lie within late-century coastal flood extents for lower-probability storms.

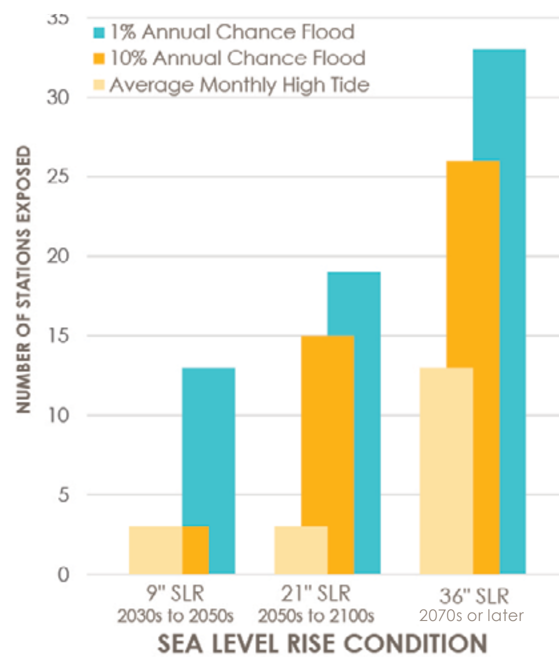
Together, law enforcement stations, fire stations, and EMS stations are expected to have the greatest share of their facilities exposed throughout the century. A quarter of Boston's law enforcement stations alone are within late-century projected flood extents for low-probability events. All essential facilities, by regulation, must have emergency protective measures in place to ensure operations continue during flood events. If an essential facility such as a fire station, EMS station, or law enforcement station is temporarily inoperable, a common practice is for the closest station to assume responsibility for covering the service population. As distance between essential service stations and locations that

EVACUATION ROUTE EXPOSURE

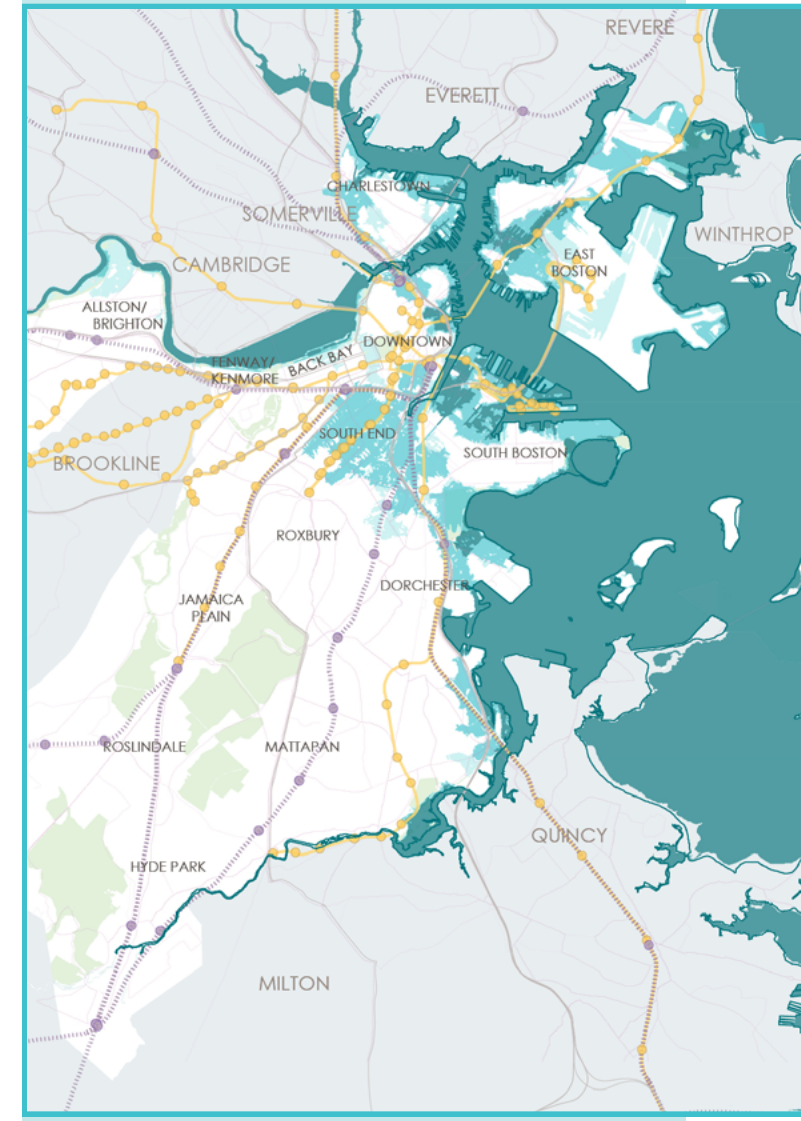
TOP 6 ROUTES BY MILES OF ROADWAY EXPOSED IN 1% ANNUAL CHANCE EVENT



MBTA STATION EXPOSURE



PUBLIC TRANSPORTATION EXPOSED TO FLOODING WITH 36" SLR



CURRENT TRANSPORTATION INFRASTRUCTURE EXPOSED TO A 1 PERCENT ANNUAL CHANCE FLOOD: NUMBER OF ASSETS AND PERCENT OF TOTAL ASSETS IN CATEGORY[71]

Facility Type	9"SLR	21"SLR	36"SLR
Major Evacuation Routes	21 (33%)	30 (48%)	39 (62%)
CA/T Assets[70]	18 (19%)	30 (48%)	61 (66%)
Water Transportation Facilities	6 (24%)	15 (60%)	18 (72%)
MBTA Stations[72]	6 (24%)	18 (17%)	32 (30%)

[69] This analysis considers exposure as opposed to expected site-specific impacts to infrastructure assets. Site-specific analysis will determine to what extent assets may already be resistant to flood impacts and should be conducted as part of resiliency planning efforts.

[71] Exposed infrastructure assets portrayed in this table are based on the information gathered and mapped by Climate Ready Boston as of July 2016. Climate Ready Boston recognizes gaps in the asset inventory exist and recommends that future assessments confirm existing data and continue to refine the dataset.

[72] MBTA stations include commuter rail and T stations, including Silver Line surface bus stations.

require public safety assistance increases, so does the response time. As response time increases, the chance of a successful outcome decreases. Associated costs could include more fire losses, an increase in completed crime, and an upturn in casualties during life-safety related incidents. The Massachusetts State Police Turnpike Headquarters is expected to face exposure to coastal storm and sea level rise impacts in the near future, while the Harbor Patrol and Suffolk County Sherriff's office will be exposed mid- to late century.

CURRENT ESSENTIAL AND PUBLIC ASSETS EXPOSED TO A 1 PERCENT ANNUAL CHANCE FLOOD:
NUMBER OF BUILDINGS AND PERCENT OF TOTAL BUILDINGS IN CATEGORY[73]

FACILITY TYPE	9"SLR	21"SLR	36"SLR
Emergency Response Facilities[74]	13 (4%)	23 (8%)	57 (20%)
Non-Emergency Medical Facilities	9 (2%)	32 (7%)	70 (16%)
Educational and Childcare Facilities[75]	12 (1%)	46 (5%)	110 (13%)

Several Boston Medical Center campus buildings in the South End and Spaulding Rehabilitation Hospital structures in Charlestown will face exposure to sea level rise in the mid- to late century.

The Boston Medical Center is the largest safety-net hospital and Level I trauma center in New England, and Spaulding Rehabilitation Hospital is the official teaching hospital for Harvard Medical School's Department of Physical Medicine. Together, the two facilities have over 600 beds. Both facilities are exposed to coastal and riverine flooding and sea level rise. Flooding of hospitals could have a significant impact on the region's healthcare system, as most hospitals within the system are currently at capacity. Existing patients may require evacuation, and incoming patients may be redirected to other medical facilities in the region, which could create overcrowding issues at other hospitals and emergency facilities, potentially resulting in delays in healthcare. Evacuation of patients carries its own risks to health and life safety, particularly to critically ill and at-risk patients, which are carefully considered prior to and during an event. Partners Healthcare is currently in the process of conducting an independent risk evaluation and actively planning appropriate resiliency measures. Partners Healthcare designed Spaulding to be climate resilient, and it is expected to be prepared for lower-probability flood events in the near future.

Most currently mapped water, wastewater, and stormwater facilities are not directly exposed to coastal and riverine flooding until late in the century.

Of the existing MWRA and BWSC water and wastewater facilities mapped by Climate Ready Boston, only the Sullivan Square Pump Station in Charlestown is currently exposed to coastal storms.[76] Of the 27 water and wastewater facilities identified within the city limits, three combined sewer overflow (CSO) facilities, nine stormwater pump stations, and three sanitary sewer pump stations are located within late-century flood extents for lower probability storms. The stormwater pump stations service evacuation routes and other transportation infrastructure; if these pumps fail, finding alternative routes would be necessary. At-risk sanitary sewer and CSO assets service growing areas within Boston and already have protection measures in place or planned to ensure continuity of operations, including redundant pumps and generators.

[73] Exposed infrastructure assets portrayed in this table are based on the information gathered and mapped by Climate Ready Boston as of July 2016. Climate Ready Boston recognizes gaps in the asset inventory exist and recommends future assessments serve to confirm existing data and fill in gaps.

[74] Emergency Response Facilities include emergency medical services, law enforcement, fire stations, hospitals, and emergency shelters.

[75] Educational and Childcare Facilities include child care centers, K–12 schools, and colleges and universities.

[76] The BWSC Wastewater Facilities Study identified the Sullivan Square Pump Station exposure, noting the consequence of failure for the pump station as roadway flooding and the required use of alternate routes.

Boston's natural and recreational resources, particularly waterfront parks, are highly vulnerable to coastal flooding.

Boston's waterfront parks, as expected, are very exposed to coastal flooding. Also exposed are large recreation areas like Victory Park and the Neponset River Estuary Area in Dorchester, the Neponset River Reservation in Mattapan, and the Charles River Esplanade. Park structures are at risk to a flood event, and trees and other vegetation in parks can be susceptible to damage from frequent saltwater exposure. Other natural resources, like Belle Isle Marsh, serve as protective barriers in a storm surge event. These assets are susceptible to a changing climate and flooding, and the City must take care to maintain them as habitats and flood protection resources. Landmark open spaces like the Boston Public Garden are at risk from future storms, while the Boston Common sits on higher ground and is not expected to be exposed to even the 1 percent annual chance flood with 36 inches of sea level rise.

Boston's energy systems are critical in a flood situation, and all essential operations rely on private companies as the first source of energy. Vulnerabilities to some energy infrastructure are understood, but additional assessments are needed.[77]

Boston's energy system is composed of many private companies that operate natural gas, petroleum, electricity, and renewable energy. Veolia Kneeland Street Plant is currently exposed to high-probability flood impacts in the near term, and approximately 250 steam delivery and distribution points could experience temporary service curtailments if the plant is to be impacted. Nevertheless, Veolia is currently planning the potential replacement of the facility; MassDOT redevelopment efforts and the new facility would be designed for climate resiliency.

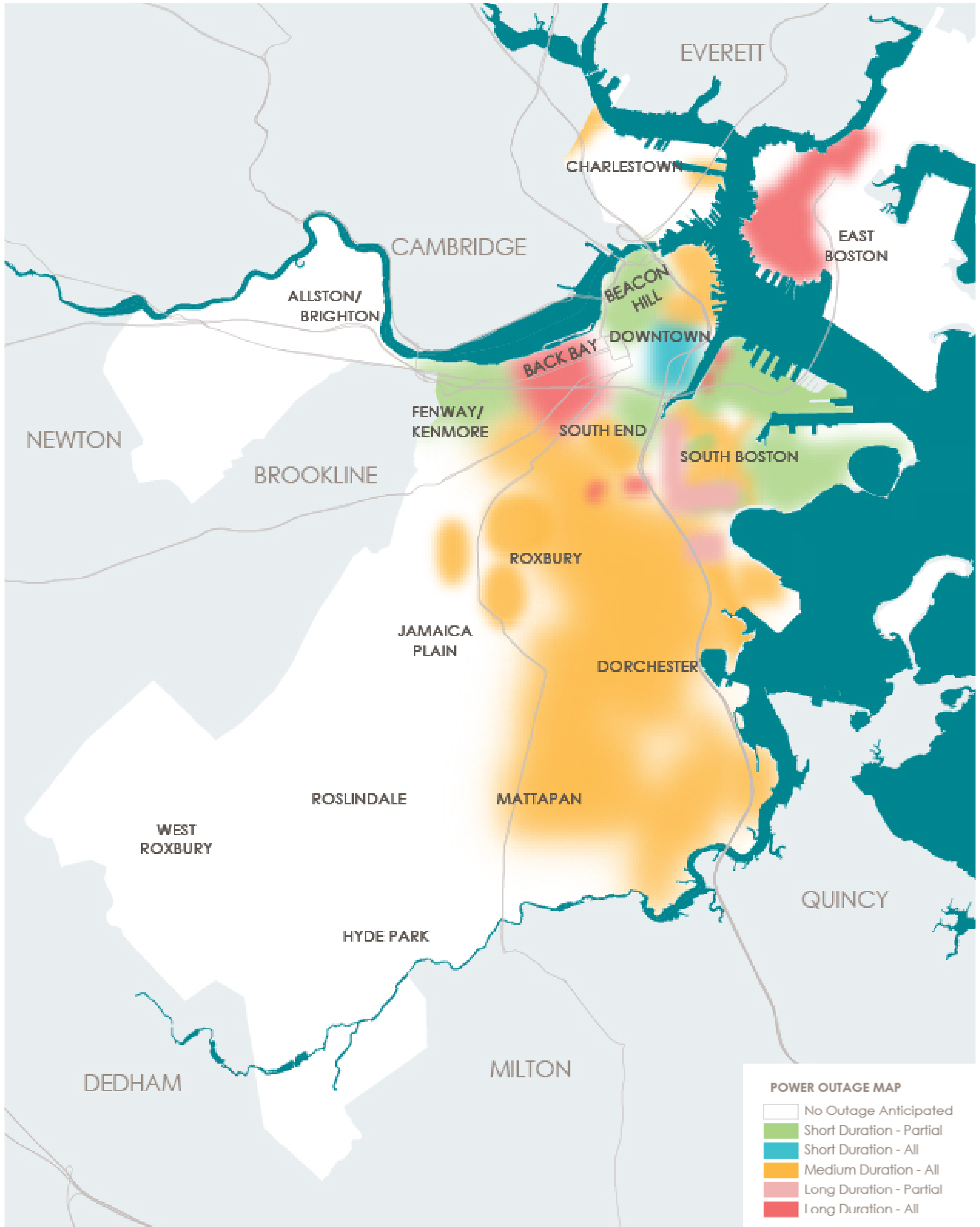
The Charlestown Wind Turbine and Mystic Generating Station are exposed to mid-century sea level rise impacts for lower probability storms. Resilience plans are in place for each of these facilities, but specific impacts for mid- to late century are not currently known. As soon as the 2070s, all of Veolia's steam supply points are expected to experience significant flooding as the result of a 1 percent annual chance event, but they could be quickly stabilized following an event, as the steam distribution system is not expected to experience impacts. Further, Veolia is currently pursuing system resilience by modifying plants to upgrade emergency and alternate power systems.

National Grid, an electricity and gas utility, has many distribution mains and gas regulator stations in Boston that will be exposed to sea level rise and coastal and riverine flooding. Half of the regulator stations that will be exposed are already protected against current storm surge, and the utility has performed its own vulnerability assessment to identify and prioritize resiliency upgrades to assets over the next three years. National Grid operates throughout Massachusetts, and infrastructure investments will not be targeted solely toward Boston.

Eversource, an electric and gas utility, has conducted an assessment of potential power outages during severe coastal storms (e.g., 1 percent to 0.1 percent annual chance) expected late century. Expected outage durations vary throughout Boston based on the vulnerability of individual electrical grid assets. The longest durations of outage due to system flood impacts are expected in East Boston and Back Bay, while Beacon Hill, Fenway/Kenmore, and South Boston are expected to have both the shortest duration and only partial outages.

[77] Information provided herein has been collected directly from the private energy companies.

EVERSOURCE POWER OUTAGE VULNERABILITIES AND DURATIONS FOR LATE-CENTURY SEVERE COASTAL STORMS



To mitigate the effects of sea level rise and climate change, Eversource is making significant investments in the local electrical grid to harden and make it more resilient to coastal storms and climate change. This is exemplified in the construction of Substation 99 on the South Boston Waterfront. The substation, which was built as a response to the rapid development and growth in the South Boston Waterfront, sits on a reinforced, elevated steel platform. Sitting nearly 26 feet above mean sea level, this substation is designed to withstand significant storm surge and flooding scenarios.

Telecommunications providers in Boston share critical infrastructure networks to provide service. Few redundancies exist, other than those built directly by providers, and essential and critical facilities could find themselves limited to radio communication in a flood event.

Telecommunication is a critical service to essential and critical facilities, particularly in times of emergency, when systems may be compromised. The timeliness of emergency medical and public safety calls and data transfer is critical for successful outcomes. Providers such as Comcast and Verizon typically deliver their services through satellite or fiber networks. Cable, land telephone lines, and cellular service for multiple carriers is often provided over shared fiber networks, reducing system redundancy between providers. Compromised fiber networks would slow communications and require customers to rely on backup communication options, such as satellite cellular services not reliant on fiber or radio frequencies. Wireless services are relied upon heavily in an emergency or flood event; this can lead to delays in the transfer of phone calls and data, particularly if fiber networks are compromised. **For this reason, individual providers work to introduce multiple redundancies within the fiber network system, and the system is continually assessed and prioritized for vulnerabilities. Fiber networks are versatile and can be quickly rerouted through alternate shared lines.**

Providers indicate they maintain a robust risk-management program in order to limit service interruptions. For example, if a single distribution facility is compromised, fiber networks allow rapid rerouting and redistribution of service, and outages are tracked via sophisticated programs that identify sites of loss. Certain providers, such as Comcast, maintain use of mutual aid and service agreements to ensure rapid distribution of generators and fuel in the case of regional disaster situations in order to speed repair services, as would be the case in a hurricane, nor'easter, or blizzard. Telephone service is prioritized as the most important communication option to maintain after emergency alert systems. Nevertheless, individuals and government agencies must consider communication backups to supplement the efforts of the providers.

Exposure of regional assets, such as the Chelsea and Everett food distribution markets and oil refineries on Chelsea Creek, will have an effect on Boston resiliency and should be considered in planning efforts.

Though not covered within the exposure and consequence analysis, Boston is dependent upon resources and assets located outside the city limits. For example, two fresh-food distributors located in Chelsea and Everett (New England Produce Center and Boston Market Terminal, respectively) have been flagged as potential vulnerabilities in Boston's food distribution system because of current and future flood risk. Furthermore, the majority of food that comes into Boston is trucked in through I-93, which is expected to be exposed to coastal and riverine flooding throughout this century.

BOSTON'S INFRASTRUCTURE INTERDEPENDENCIES

The relationships and dependencies between different infrastructure networks are complex and intertwined. Each infrastructure system depends on others to sustain operation, as illustrated through the descriptions above. As part of the development of the Vulnerability Assessment, IAG members provided input regarding potential interdependencies between infrastructure assets and systems.[78] The Vulnerability Assessment identified infrastructure systems that IAG organizations rely on for their core functions, as well as anticipated consequences of full or partial system failures.

Members of the IAG have identified continued functionality of the city's transportation infrastructure as a top resiliency priority. Many members have identified road and bridge functionality as a key critical requirement so citizens can evacuate; emergency vehicles can pass; maintenance trucks can reach impacted electric, communication, and water/wastewater assets for swift repair; and hospitals and other emergency facilities can continue to receive food, water, and medical supplies. In turn, the transportation system relies on continued access to electricity and communications systems, so tunnels may remain open, and any blocked paths are cleared quickly or detours swiftly communicated.

Boston's energy systems are also critical in a flood situation, and all critical and essential operations rely on private companies as the first source of energy. Though critical and essential operations most often have redundancies in their energy systems, back-up energy sources have limited capacity and cannot sustain operations for an extended period of time. For example, water and sewer systems rely on energy to operate pump stations and process and treat wastewater; communication systems require significant amounts of electricity to run and to keep equipment cool; emergency shelters require heat, water and wastewater, and communication systems to be operational at all times; and hospitals need energy to continue to operate life-saving equipment.

[78] Many details related to site-specific interdependencies are not described within this report due to data limitations and privacy or security concerns.

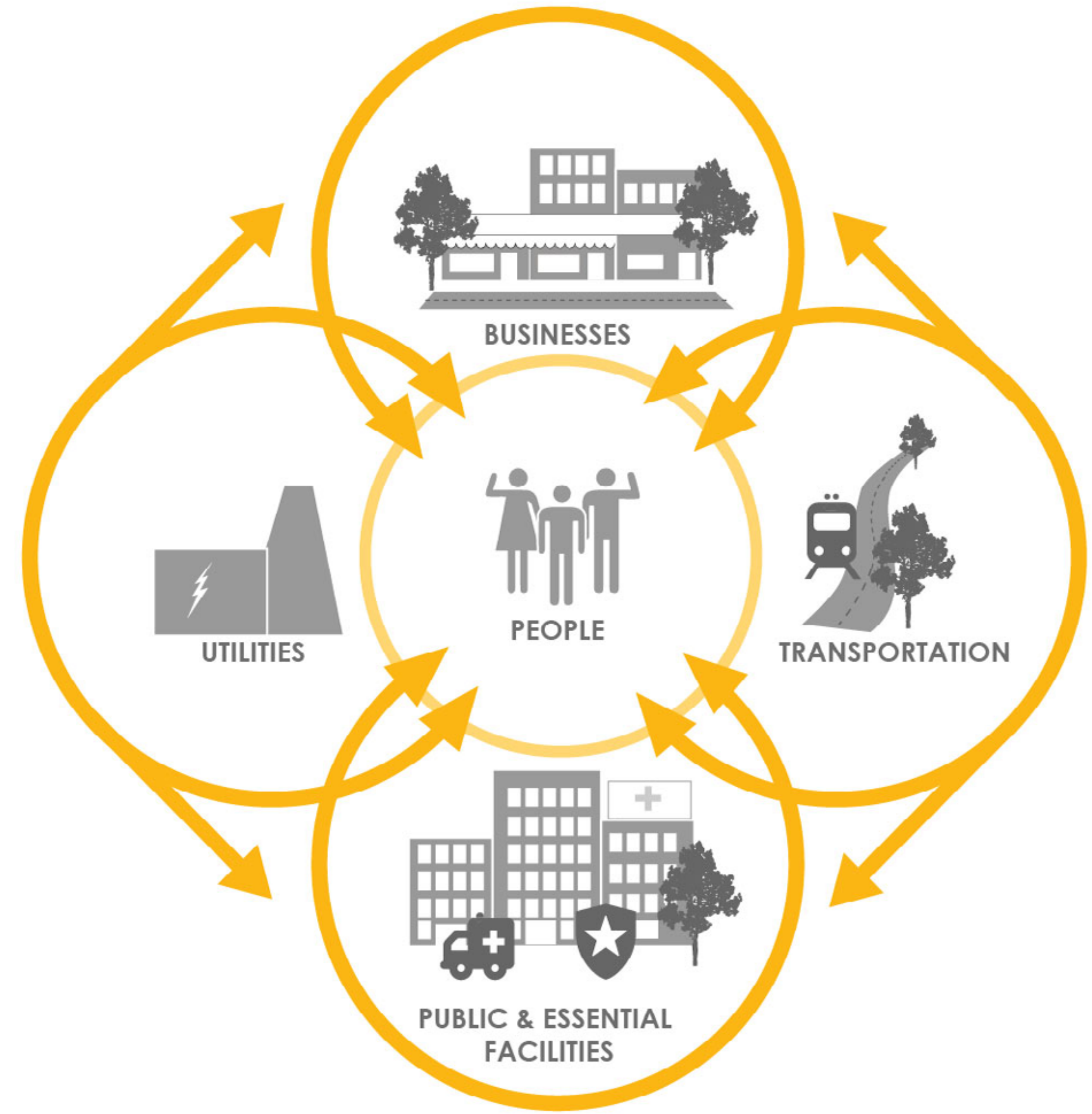
Nonessential assets are also affected by energy loss. Many buildings house primary and redundant energy assets, such as generators, in basements, which will likely be the first portions of buildings to flood. If commercial buildings are without power for long periods of time, major productivity and revenue losses may be experienced. If private energy assets are impacted by flooding, repair crews require clear roads and bridges to access sites and transport heavy equipment. Steam-generating plants also rely on continuous water supply for operations.

MWRA and BWSC are highly dependent on each other to ensure continued operation of Boston's water and wastewater system. MWRA operates water supply and treatment facilities within Boston, while BWSC handles potable water delivery and water/wastewater conveyance and pumping. If one of the two operations fail, then potable water and sewage treatment operations in Boston will be impacted. Uninterrupted service of water and wastewater systems is essential for public health and safety facilities, such as hospitals and emergency shelters. Although water and wastewater operations rely on energy systems, failure to the system may be mechanical and require on-site repairs. As such, clear transportation routes are critical for continued operations of water and wastewater systems, particularly in the case of flood events.

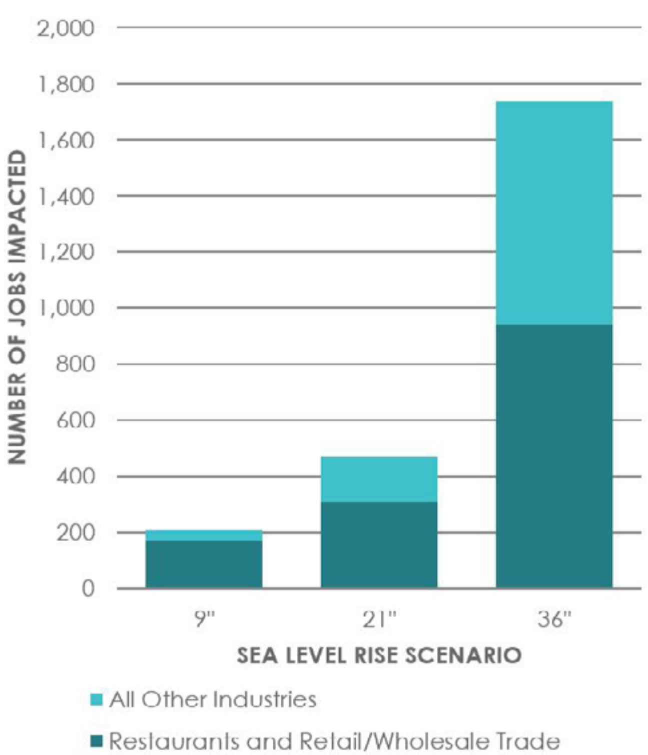
All of these facilities require fuel to run generators in the case of power outages as well as to operate key equipment at their facilities. Fuel is often a key area of concern post-disaster, and critical shortages are common simply because of the compounded need. These shortages can be significantly exacerbated when fuel provider facilities themselves are compromised or transportation pathways are blocked, damaged, or submerged, leading to more severe cascading impacts across the infrastructure system.

Communication assets are critical in any emergency situation. Radio, telephone, and television-transmitting stations are necessary to keep lines of communication open between public safety agencies and the public so situational updates can continue to be conveyed. Moreover, communication interruptions can result in the loss of information distribution and potentially disrupt interactions among hospitals, government agencies, police, and EMTs.

Our daily lives depend on a complex, interconnected system.



EMPLOYMENT IMPACTS OF COASTAL FLOODING



CALCULATING ANNUALIZED LOSSES

Annualized losses are calculated by multiplying the potential consequence in dollars (such as damage costs for the 1 percent annual chance event) by the probability of occurrence for that consequence (1 percent annual chance). This allows for comparisons of different events across time. Depending on the circumstances, smaller but higher-probability storm events may actually yield more costs to the community over time than larger, lower-probability storm events. The graphic below displays this effect; the 10 percent annual chance events consistently carry the highest annualized values throughout the century within the City of Boston.

As flood risk increases this century and beyond, total expected annualized losses increase dramatically; severe storms are expected to become increasingly more frequent.

ECONOMY

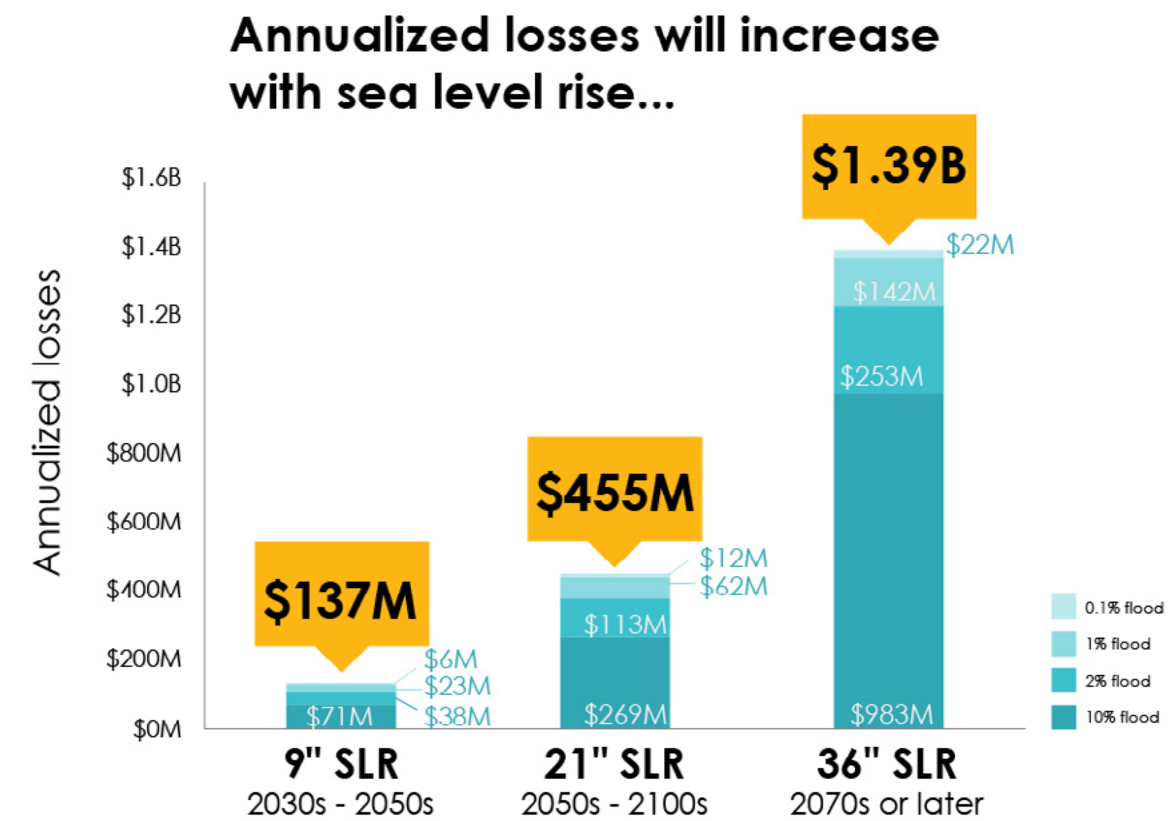
For all sea level rise conditions, restaurants, real estate, retail and wholesale trade, and transportation industries are consistently the most affected by business interruption due to coastal and riverine flooding.

Combined, the top four economic industries in Boston expected to be affected by business interruption account for over 50 percent of the expected business interruption impacts for the city (averaged across all sea level rise conditions). Business interruption also impacts jobs in Boston, as a reduction in sales and revenues, as well as temporary business closure, may ultimately reduce the number of jobs required to support the economy. The restaurant and retail industries lead with the most jobs impacted for each sea level rise condition, accounting for 80, 48, and 52 percent of the total annual jobs expected to be lost for early-, mid-, and late-century impacts, respectively. That these industries are affected by coastal and riverine flooding is another demonstration of how vulnerable populations will be impacted more significantly by climate change. Restaurant and retail sectors tend to provide jobs for low- to moderate-income people, and those who lose their jobs or experience reduced work hours may struggle financially, even more so if they are also burdened with structural damage or relocation costs.

SUMMARY AND ANNUALIZED RESULTS

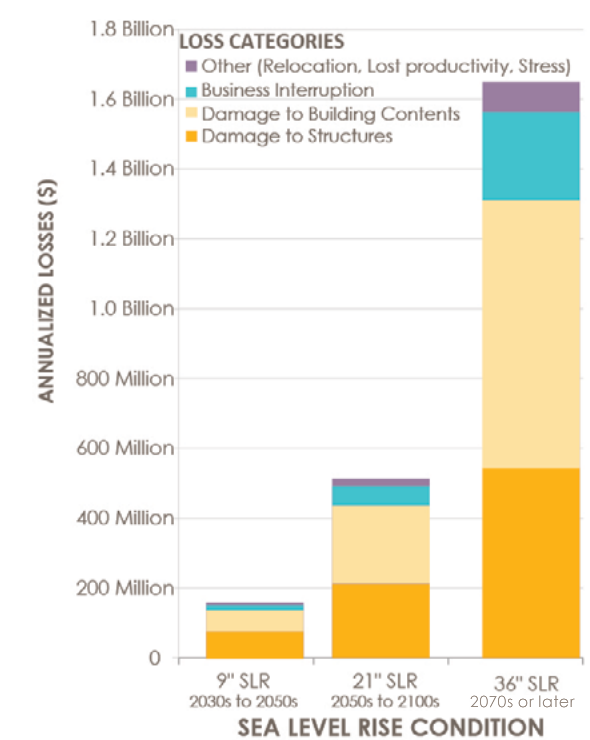
Late-century sea level rise conditions combined with coastal storms make South Boston, Downtown, and the South End[79] the top three impacted neighborhoods in terms of expected costs of structure damage, contents losses, relocation costs, and stress factors in that time period, by a wide margin.

[79] Losses to South End are not expected to begin in earnest until late in the century.



Even considering only 9 inches of sea level rise, Boston is expected to experience roughly $137 million in annualized direct physical damage, stress factor, and displacement costs. These impacts are expected to increase tenfold to nearly $1.39 billion by late in the century for the four event scenarios considered in the Vulnerability Assessment (10 percent, 2 percent, 1 percent, and 0.1 percent annual chance flood events). Costs related to structural damage and contents losses make up the majority of these damage costs, averaging 95 percent of all direct damage costs across all three sea level rise conditions. South Boston accounts for the highest annualized damages for each sea level rise condition, comprising between 32 and 47 percent of the city's total annualized direct damage costs. The sharpest increase in loss between mid- and late century is expected to take place in the South End, with a hundredfold increase in total annualized losses expected.

CITYWIDE ANNUALIZED LOSSES BY LOSS CATEGORY



Losses in the bar graph are expected total loss costs for direct damage, relocation, mental stress and anxiety, lost productivity, and business interruption. All values consider only present assets located within projected flood area.

ANNUALIZED IMPACT TOTALS BY NEIGHBORHOOD AND CITYWIDE BUSINESS INTERRUPTION

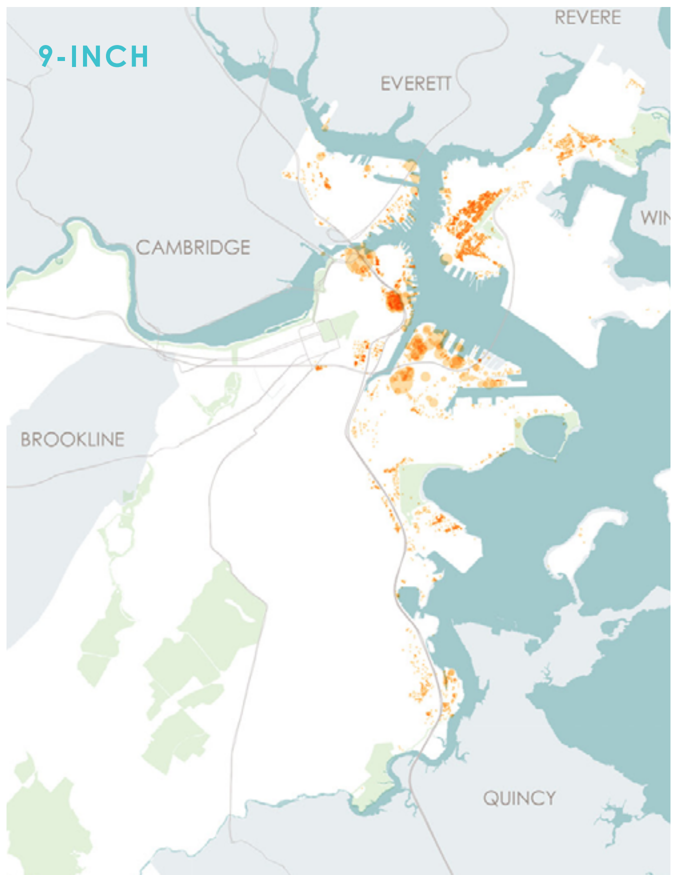
	9" SLR		21" SLR		36" SLR	
Neighborhood	**$**	**% Boston Total Losses**	**$**	**% Boston Total Losses**	**$**	**% Boston Total Losses**
South Boston	$64.6M	48%	$191M	37%	$450M	27%
Downtown	$44M	31%	$104M	20%	$289M	17%
East Boston	$13.3M	8%	$87.1M	17%	$179M	11%
Charlestown	$8.9M	6%	$42.8M	8%	$120M	7%
Dorchester	$6.2M	4%	$26.9M	5%	$92.5M	6%
South End	$27k	<1%	$2.2M	<1%	$218M	13%
Roxbury	<$1k	<1%	$189K	<1%	$33.8M	2%
Back Bay	<$1k	<1%	$72K	<1%	$7.4M	<1%
Allston	<$1k	<1%	$254K	<1%	$7.1M	<1%
Fenway/Kenmore	<$1k	<1%	<$1k	<1%	$1.6M	<1%
Harbor Islands	$252k	<1%	$284K	<1%	$328K	<1%
Citywide Business Interruption	$19.7M	13%	$63.8M	12%	$283M	17%
Boston Total	**$157M**		**$518M**		**$1.68B**	

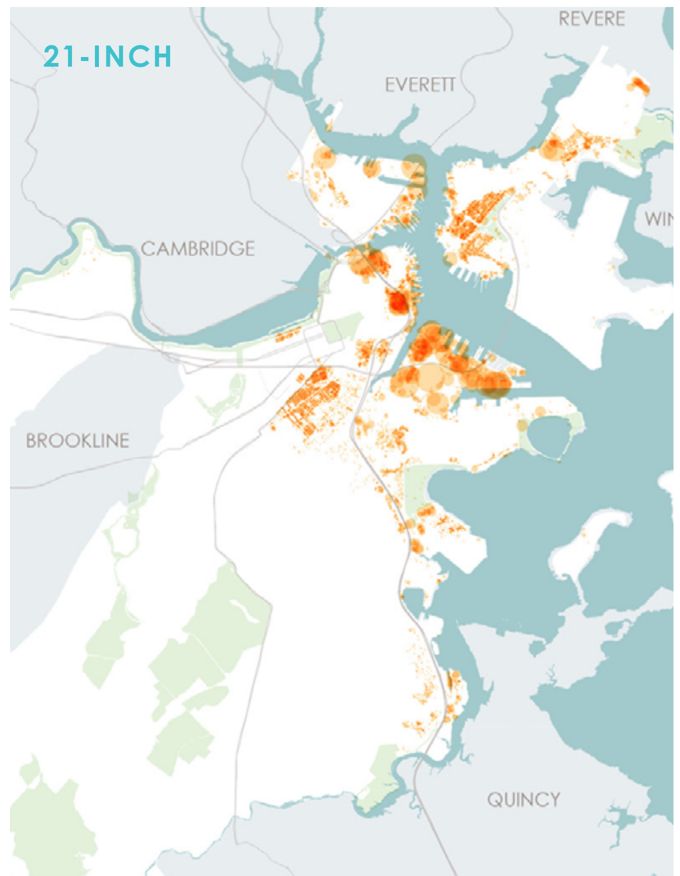
ANNUALIZED DIRECT PHYSICAL DAMAGE, STRESS FACTORS, AND DISPLACEMENT COSTS FOR THE 36" CLIMATE CONDITION BY NEIGHBORHOOD

	DIRECT PHYSICAL DAMAGE	STRESS FACTORS	DISPLACEMENT COSTS	TOTAL
South Boston	$431M	$4.7M	$14.3M	$450M
Downtown	$276M	$5.4M	$7.3M	$289M
South End	$193M	$14.1M	$10.9M	$218M
East Boston	$163M	$10.2M	$6.4M	$179M
Charlestown	$115M	$2M	$3.4M	$120M
Dorchester	$86M	$3.2M	$3.4M	$92.5M
Roxbury	$32.6M	$240K	$970K	$33.8M
Back Bay	$6.6M	$470K	$310K	$7.3M
Allston	$7M	$30K	$120K	$7.1M
Fenway	$1.5M	$120K	$50K	$1.6M
Harbor Islands	$320K	-	$10K	$330K
Boston Total	**$1.3B**	**$40.4M**	**$47.1M**	**$1.4B**

Note: Values consider only present-day people and structures currently located within the projected flood area

ANNUALIZED LOSSES FROM BUILDINGS,
9-INCH, 21-INCH, AND 36-INCH SEA LEVEL RISE CONDITIONS

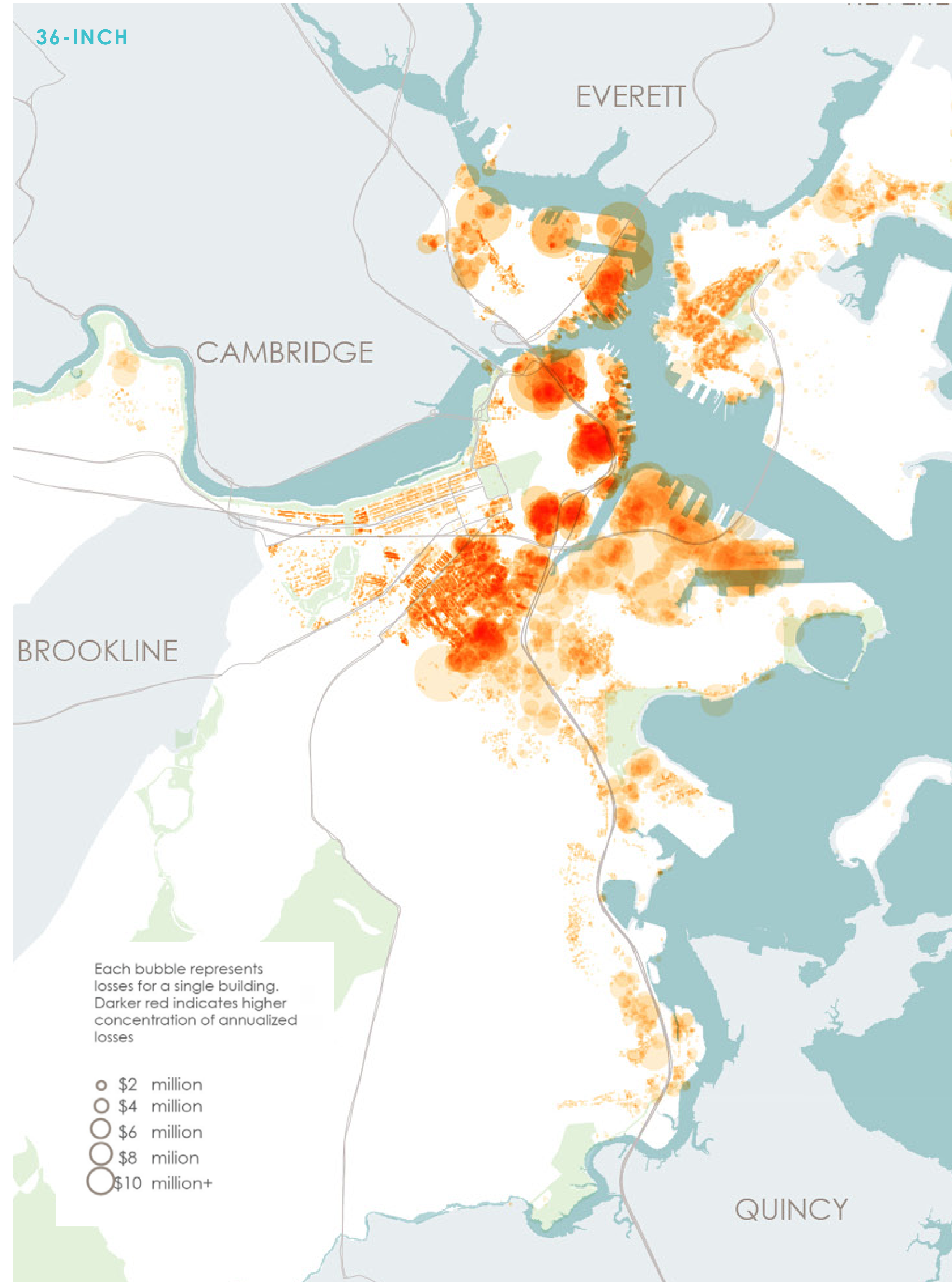




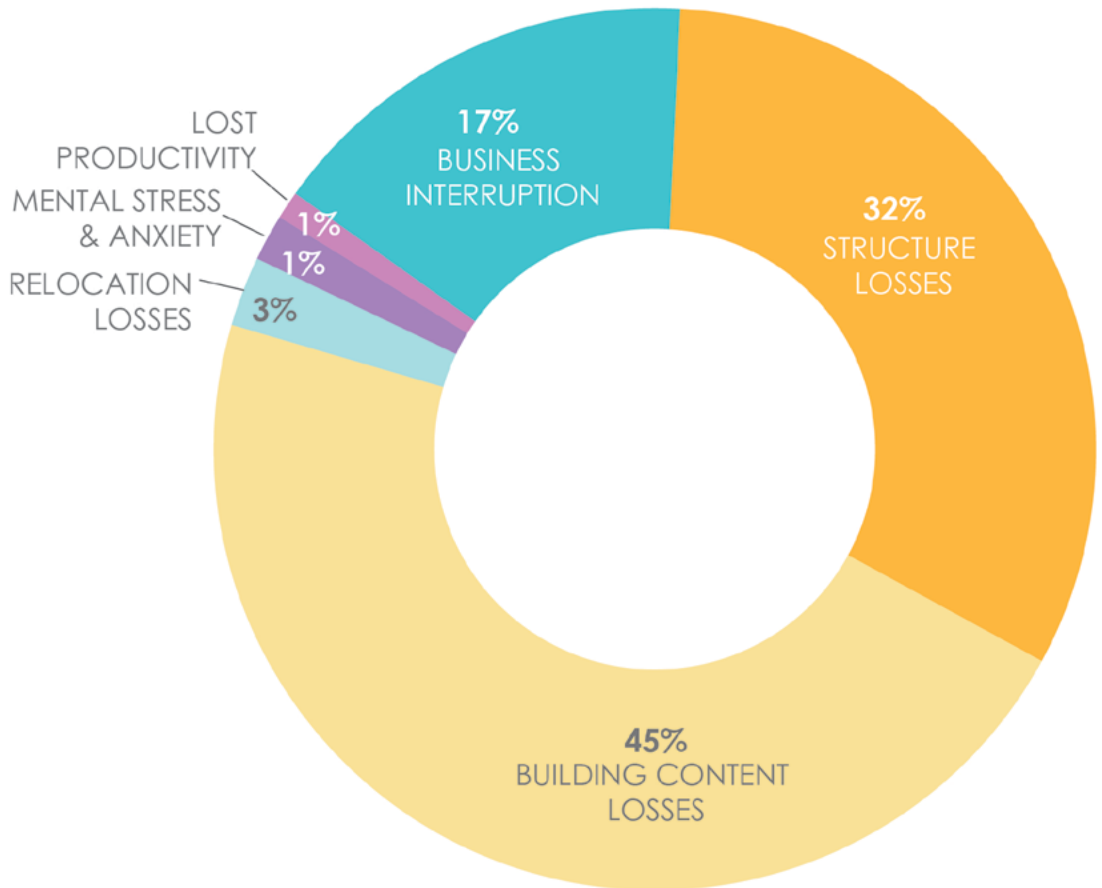
The above map demonstrates expected annualized structure and contents losses per building for the 36-inch sea level rise condition.[80]

[80] These expected losses only address the building stock current to 2016 and do not take into consideration development changes or adaptation. Each bubble depicts a single structure, with the size of the bubble demonstrative of the magnitude of expected impacts to that structure. Concentrations of loss are depicted with darker colors.

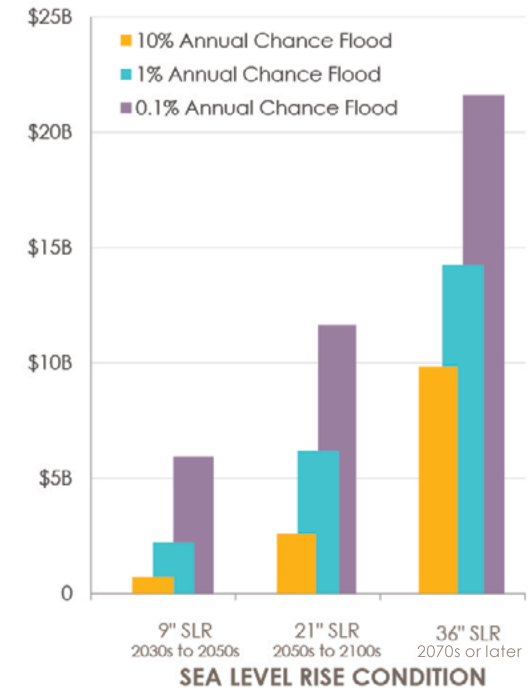
High-rise buildings, concentrated in Downtown and South Boston, show heavier impacts for several reasons. Not only are these structures larger, but they typically penetrate more deeply into the earth to accommodate their size and have more sophisticated and costly mechanical, electrical, and plumbing systems, often located in the basements of these structures. Impacts to residential structures, however, should not be discounted. The majority of loss expected throughout the city will be to residential properties.



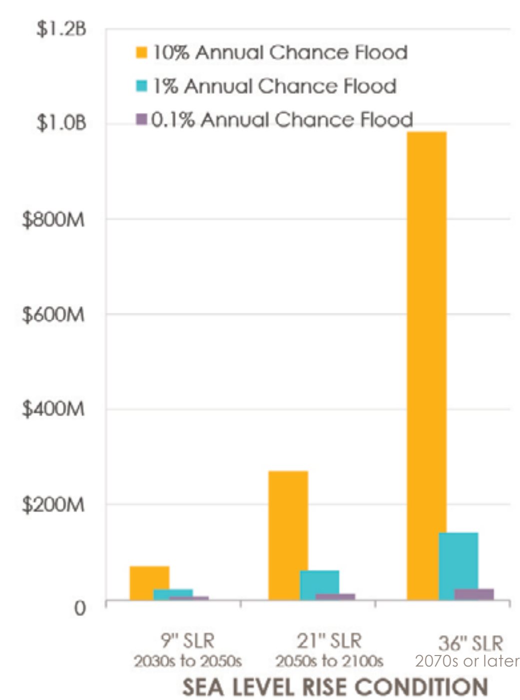
CITY OF BOSTON ANNUALIZED LOSSES
36 INCH SEA LEVEL RISE CONDITION



CITYWIDE ECONOMIC LOSSES



CITYWIDE ANNUALIZED LOSSES



Business interruption is expected to total nearly $250 million in annualized damages, accounting for 15 percent of mid- to late century total damages.

In addition to the $1.4 billion in expected annualized direct physical damage, stress factor, and displacement costs for the 36-inch sea level rise condition, annualized economic output losses caused by business interruption within Boston total at least $283 million.[81] This includes $201 million in direct output losses, which are sales and revenues lost by businesses that must close or relocate while they repair flood-damaged structures or restock inventory. It also includes $82 million of losses in industries that support the directly impacted businesses and losses due to decreased consumer spending. This brings the total annualized losses expected for the 36-inch sea level rise condition to $1.7 billion, with business interruption losses accounting for 17 percent of this total.

[81] Business interruption values only consider businesses on floors that are directly impacted by flood events and assume that all businesses eventually reopen. Direct losses are calculated within Boston, and indirect and induced losses are only modeled throughout Suffolk County. In actuality, the entire building will often experience business interruption (though no reliable resource exists to consistently calculate business interruption impacts to an entire structure), many flooded businesses may not ever reopen after being directly flooded, and economic impacts could extend nationally or internationally, depending upon industries affected. As such, these results are considered the minimum business interruption consequences of a regional flood event. See Appendix for more detail on methodology.

All damage figures presented in this Exposure and Consequence Analysis may be considered the lower bound of actual economic losses that can result from regional and site-specific[82] coastal and riverine flooding for the below reasons. A full explanation of the limitations associated with this assessment can be found in the Appendix.

- Short- and long-term impacts to the local and federal government that follow a flood event, such as dispensing additional public aid and mobilizing emergency management crews, are not reflected in the damage costs. Such costs are based on a variety of factors (including the scale and magnitude of the event, as well as the built and natural environment and population contexts) and are extremely difficult to predict.
- Businesses located above the second floor of a multistory building are not considered in this analysis, even though those businesses may also experience closures or damage (such as mold accumulation) if power and water are not operating in the building. Further, code compliance actions that may be triggered by repairs (such as electrical and fire suppression systems) can run through the entirety of a building, depending on the specifics of the structure, further increasing restoration costs; such costs are not considered in this analysis.
- Impacts to the economy assume all businesses will eventually reopen, yet in reality almost 40 percent of all small businesses never reopen following a disaster.[83]
- Impacts to supporting economic industries and spending patterns are only acknowledged within the context of Suffolk County. Boston has broader economic relationships, which would increase the reverberation of impacts to the regional and broader economy.
- Calculations consider zero growth or change from the present-day population and built environment. Values are based on the imposition of current climate conditions on the current-day built environment.

[82] Most losses, except for business interruption, are calculated on a per-structure basis.

[83] Source: "National Flood Insurance Program: Protecting Your Business." Federal Emergency Management Agency. http://www.fema.gov/protecting-your-businesses.

Climate Resilience Initiatives

Guided by the Vulnerability Assessment findings, which identified and quantified the impacts of future climate change, the City should undertake a set of climate resilience initiatives to address Boston's climate risks. These initiatives will increase Boston's ability to **thrive** in the face of intensifying climate hazards, leading to **stronger neighborhoods** and **improved quality of life** for all residents.

Image courtesy of Bud Ris

The climate resilience initiatives build on a broad set of efforts undertaken to date by the City and other actors to prepare Boston for climate change. To develop the initiatives, Climate Ready Boston reviewed past climate adaptation plans, interviewed a broad range of local stakeholders, and examined best practices from other cities across the world that are contending with climate change impacts.

The City will need dedicated public and private partners, as well as significant additional resources, to advance these initiatives and implement comprehensive climate adaptation.

Climate Resilience Principles

Climate Ready Boston draws on five principles for successful resilience to climate change based on lessons from other cities. These principles are outlined below:

Image courtesy of Sasaki

Generate multiple benefits. Effective climate resilience initiatives both reduce risks from climate hazards and create other benefits. Resilience initiatives that produce multiple benefits generate more resources to support their implementation and sustainability. Flood barriers that also provide recreational open space, developable land, or upgraded roadways represent examples of multiple-benefit solutions. Non-physical interventions also can offer multiple benefits, such as programs that help businesses and households make operational changes to reduce their flood risk while also lowering utility costs or reducing insurance premiums. Multiple-benefit approaches enable Boston to address some of the other pressing challenges that it faces beyond climate risks.

Incorporate local involvement in design and decision-making. Effective resilience initiatives require on-the-ground knowledge and sustained community support for implementation and long-term operations and maintenance. Local stakeholders can help illuminate critical resilience opportunities in their communities and generate creative ideas for solving multiple challenges at once.

Climate Ready Boston / Boston Harbor Now Workshop

Create layers of protection by working at multiple scales. Layers that are independently effective can also work together to provide mutual support and reduce the risk of a failure associated with a single line of defense. For example, to address extreme heat, adding green infrastructure (e.g., increasing tree canopy), in combination with building-scale adaptations (e.g., using cool roofing and paving materials or increasing energy efficiency), is more effective than doing either independently. Shading from the tree canopy reduces the cooling load on the building, and the retrofitted building radiates less heat, with a failure to either layer having less impact because of the other.

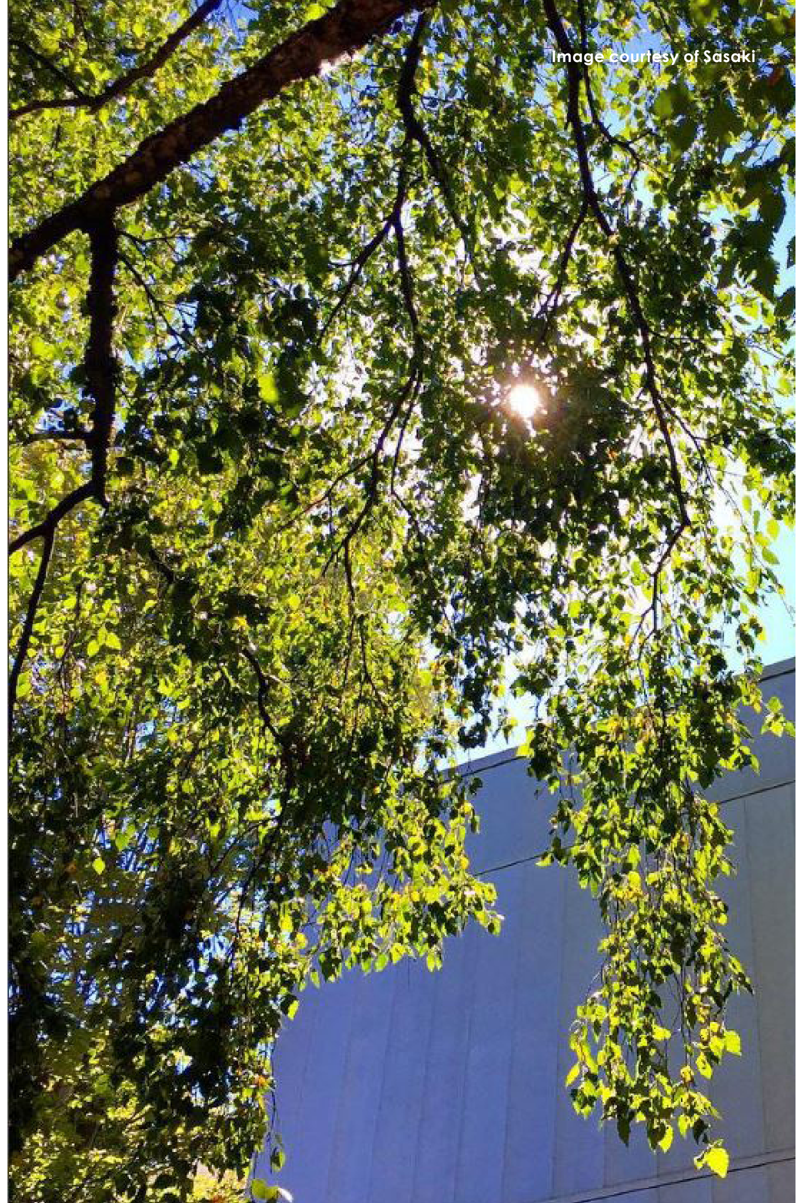


Image courtesy of Sasaki

Leverage building cycles. Buildings and infrastructure experience regular cycles of rehabilitation and replacement over time. Taking adaptation actions within the context of the building cycle can reduce disruption and cost, as in the case of green infrastructure installed as part of a road reconstruction project, rather than as a standalone project that would still require digging up roads. While the building cycle progresses, operational changes, as opposed to physical adaptations, can be made to reduce risks. For example, retailers can move the inventory stored in the basement of their stores onto shelves to reduce flood damage in the near term, before local flood defenses are built.

Image courtesy of Sasaki

Image courtesy of Sasaki

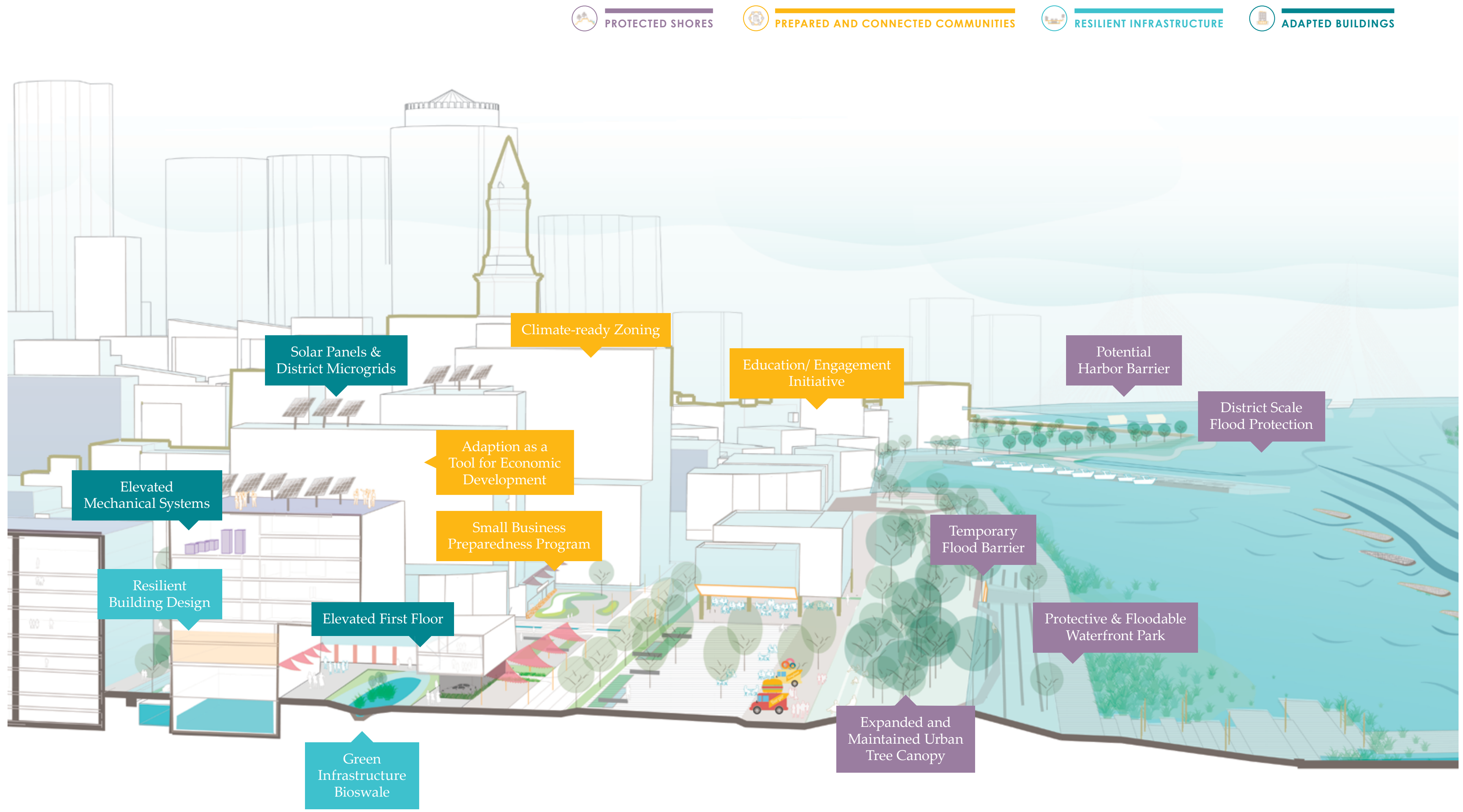
Design in flexibility and adaptability. Climate conditions will continue to change over time, and climate resilience initiatives must be designed to adapt to them. For example, the 24-hour rainfall for a 10-year storm is projected to increase through the century. To be effective, the stormwater system must be flexible enough to adapt to this increase in extreme precipitation. In practice, this often means decentralized, distributed stormwater storage across cities that can be expanded without disrupting the gray stormwater system. Similarly, the elevation of 1 percent annual chance floods is also projected to increase throughout the century. Buildings can be built today with high ground-floor ceilings so that the ground floor can be raised as sea levels rise over time, without creating undesirably low floor-to-ceiling heights.

Layers and Strategies

Climate resilience initiatives are actions that Boston can undertake to improve its preparedness for climate change. They respond to the geographic extent, frequency, and severity of the three key climate hazards the city faces. The initiatives tied to extreme heat and stormwater flooding are meant to be applied citywide, given the geographic dispersion of those hazard impacts, while those tied to coastal and riverine flooding are targeted to the specific waterfront and inland areas exposed to this hazard.

The climate resilience initiatives have been organized into 5 layers and 11 strategies. The first layer is an understanding of Boston's future climate conditions, the foundation on which other initiatives rely. The remaining layers represent an approach to building resilience at different scales: the community, shoreline, infrastructure assets, and buildings. The layers are designed to support and reinforce each other. For example, a building that has been retrofitted for flood risk (Adapted Buildings) is more resilient if it sits behind a district-scale flood protection system (Protected Shores) that prevents the flooding of adjacent buildings and streets. It is even more resilient when its users are aware of and have prepared for climate risks (Prepared and Connected Communities), and the manmade and natural infrastructure that serves it is climate ready (Resilient Infrastructure).

Within each layer, individual initiatives are clustered under strategies, with the initiatives under each strategy reinforcing each other and driving toward related outcomes.



VISUALIZING MULTIPLE LAYERS OF CLIMATE READINESS

LAYERS	OUTCOMES
Updated Climate Projections	Ensure that decision making in Boston is informed by the latest Boston-specific climate projections.
Prepared and Connected Communities	Support educated, connected, empowered communities in pursuing operational preparedness, adaptation planning, and emergency response.
Protected Shores	Reduce Boston's risk of coastal and riverine flooding through both nature-based and hard-engineered flood defenses.
Resilient Infrastructure	Prepare the infrastructure systems that support life in Boston for future climate conditions and create new resilient systems.
Adapted Buildings	Create a regulatory environment and financial and other tools to promote new and existing buildings that are climate ready.

Layer 1

UPDATED CLIMATE PROJECTIONS

Strategy 1: Maintain up-to-date information on future climate conditions in Boston

INITIATIVE 1-1. UPDATE BOSTON-AREA CLIMATE PROJECTIONS PERIODICALLY

The City should establish the Greater Boston Panel on Climate (GBPC) to serve as the continuation of the Boston Research Advisory Group (BRAG), which developed the Climate Projection Consensus for Climate Ready Boston. The GBPC should consist of leading climate scientists from local and regional institutions, organized into working groups focused on key climate factors, such as extreme temperatures, sea level rise, coastal storms, and precipitation.

The GBPC should be charged with two responsibilities. First, the GBPC should produce an updated set of climate projections for the Boston area every five years, building on the 2016 Climate Projection Consensus. These projections should reflect the most up-to-date data and theoretical understanding and include consideration of multiple emissions scenarios and time periods, extending at least 100 years in the future. As part of the process of developing climate projections, the GBPC also should fill research gaps in local climate change knowledge. Second, the GBPC should assist local and state agencies in applying those conclusions to policy, design, and regulation. In particular, the GBPC should provide information to the Infrastructure Coordination Committee to support the development of planning and design standards (see Initiative 6-1, p.118), and to the Boston Planning and Development Agency to support efforts to incorporate climate readiness into zoning standards and land-use planning (see Initiative 9-2, p.135).

The Environment Department should oversee the GBPC's work, and the City should identify funding for the work of the GBPC.

INITIATIVE 1-2. CREATE FUTURE FLOOD MAPS TO SUPPORT PLANNING, POLICY AND REGULATION.

The City should create a set of flood maps that show the extent and depth of future flooding, possibly including indications of wave action, moving water, and channelization hazards. The future flood maps should be based on the latest climate projections from the Greater Boston Panel on Climate (GBPC; see Initiative 1-1, p. 84), as well as policy decisions regarding acceptable levels of risk. These policy decisions should be made in collaboration with local and state agencies and will require consideration of four key parameters:

- **Emissions scenario.** The GBPC will create climate projections for multiple greenhouse gas emissions scenarios. Future flood maps should reflect a decision regarding which emissions scenario is the most appropriate to use for planning, policy, and regulation. For example, a decision to use the business-as-usual scenario would mean setting a lower level of acceptable risk and more stringent regulatory standards than a decision to use the moderate-reduction emissions scenario.
- **Projection likelihood.** Each emissions scenario includes a range of likely outcomes for sea level rise and other climate factors. Future flood maps should reflect a decision about which outcome from within this range should be used. For example, the median projection of sea level rise has a 50 percent chance of being exceeded; a stricter standard may require that the sea level rise assumption used should have at most a 15 percent chance of being exceeded.
- **Appropriate time periods.** The GBPC will create climate projections for multiple time periods. Future flood maps should reflect multiple time periods, corresponding to decisions regarding the minimum expected life of buildings and infrastructure. This is critical for planning, designing, and regulating for the flood risk an asset will face during its expected life, rather than just the risk that it faces today. For example, in its Climate Change Preparedness Checklist, the Boston Planning and Development Agency currently assumes that large buildings in Boston have a design life of at least 60 years.
- **Flood probabilities.** Future flood maps should show the extents and depths of various probabilities of flooding. These multiple probabilities will support decisions regarding acceptable levels of risk. For example, an infrastructure agency may decide that a local road serving a very small area should face no more than a 1in 100 annual chance of inundation during its useful life, while a major artery or evacuation route should face no more than a 1 in 1,000 annual chance of inundation.

Local and state agencies, with guidance from the Environment Department, should use the resulting flood maps for planning, policy, and regulations. For example, the Infrastructure Coordination Committee should incorporate them into planning and design standards (see Initiative 6-1, p.118), and the Boston Planning and Development Agency should use them for setting appropriate zoning standards within the future floodplain (see Initiative 6-1, p.118).

In conjunction with the work of the GBPC, the City should update future flood maps every five years, reflecting updated climate projections, ongoing policy decisions regarding acceptable levels of risk, and changes in the natural and built environment.

CASE STUDY: NEW YORK CITY PANEL ON CLIMATE CHANGE

In 2008, Mayor Bloomberg convened the New York City Panel on Climate Change, an independent body of scientists, to develop localized climate projections. In September 2012, the New York City Council passed Local Law 42, which requires the NPCC to meet at least two times per calendar year to review the most recent scientific data on climate change and its potential impacts on New York City. The NPCC is required to release updated local climate change projections at least every three years, with the last set of projections released in 2015.

CLIMATE READY BOSTON'S FUTURE FLOOD MAPS

Climate Ready Boston produced maps that reflect future conditions for three sea level rise scenarios (9, 21, and 36 inches) for the purpose of conducting high-level assessments of flood risk and developing climate resilience initiatives. These scenarios are not necessarilythe appropriate ones for detailed planning and regulation.

STANDARDS FOR ACCEPTABLE FLOOD RISK LEVELS

FEDERAL FLOOD RISK MANAGEMENT STANDARD

In January 2015, President Obama signed Executive Order 13690, which established national flood risk standards for all federally funded projects in and near floodplains. Under the order, federally funded projects must adhere to one of three standards. They can use projections informed by the best available data and methods, build two feet above the current 1 percent annual chance flood elevation for standard projects and three feet above for critical buildings like hospitals and evacuation centers, or build to the 0.2 percent annual chance flood elevation.

DUTCH FLOOD RISK MANAGEMENT STANDARD

The Netherlands government recently revised flood risk management standards for national flood defenses. The new standards are based on the level of protection required to provide a basic level of safety for people behind flood defenses and to minimize severe economic losses. For flood defense systems to be considered to provide a basic level of safety, the individual annual risk of dying due to flooding at a particular location must no higher than 1 in 100,000, taking into consideration evacuation possibilities. The economically efficient level of protection is that which minimizes the sum of expected damages and required protection investments. Where one of the two standards (basic safety and economic efficiency) leads to a higher level of protection, the stricter standard is used.

Sources: "Federal Flood Risk Management Standards." FEMA. http://www.fema.gov/federal-flood-risk-management-standard-ffrms.

H. van der Most, I. Tanczos, K. M. de Brujin, and D. Wagenaar. "New Risk-Based Standards for Flood Protection in the Netherlands." Paper Presented at the Sixth International Conference on Flood Management, Sao Paulo, Brazil. 2014.

Layer 2

PREPARED AND CONNECTED COMMUNITIES

Boston residents,

businesses, institutions, and community groups are essential partners in climate adaptation, given their role as the day-to-day stewards of Boston's neighborhoods. In preparing for climate change, the City will work closely with these groups to learn from their local expertise, identify and incorporate their adaptation-planning priorities, overcome challenges to successful adaptation, and partner in planning efforts. Throughout both adaptation planning and implementation efforts, the City will engage in two-way communication with residents, businesses, institutions, and community partners, wherein it is actively engaged in both sharing and receiving information.

The City will connect with residents through a variety of methods and channels, with a special focus on ensuring that it reaches socially vulnerable populations. Recognizing Boston's large population of renters and students, the City will make a strong effort to connect these groups with information and resources and engage them in planning efforts. The City will provide pathways for residents to participate in climate-related volunteering efforts, such as the Boston Medical Reserve Company, and to take part in Resilience Area Planning Committees. To conduct effective outreach to Boston's population, City agencies will partner with a broad range of resilience-focused nonprofits, business groups, community development corporations, and other community-based organizations.

Building on its commitment to inclusive growth, the City will use its climate adaptation efforts as a tool to enable more residents to fully participate in Boston's economy. Where possible, the City will link resilience investments to investments in housing, transportation, open space, job growth, and neighborhood services in order to increase safety, economic opportunity, and livability for all residents. Because resilience improvements may increase property values and thereby potentially affect affordability for residents, the City, led by the Office of Resilience and Racial Equity, will work to address these impacts by developing a resilience and racial equity toolkit. This toolkit can be used to evaluate policies and practices in order to make sure that racial equity and social cohesion form the foundation of the City's decision-making processes.

Strategy 2: Expand education and engagement of Bostonians about climate hazards.

INITIATIVE 2-1. EXPAND CITYWIDE CLIMATE READINESS EDUCATION AND ENGAGEMENT CAMPAIGN

The City should leverage its existing emergency preparedness and climate adaptation outreach efforts to develop and implement a long-term education campaign targeted to all Bostonians with a special focus on socially vulnerable populations. In the short term, the City's education campaign should focus on sharing the results and implications of Climate Ready Boston with all Boston residents. In the intermediate and longer term, the campaign should support both individual climate preparedness efforts and neighborhood engagement in district-scale climate adaptation planning through the Local Climate Resilience Committees *(see Initiative 4-2, p.102)*.

This education campaign should be coordinated by a consortium of partners within the City. The consortium can include Greenovate Boston and the Environment Department, the Office of Emergency Management, the Boston Public Health Commission, the Office of Neighborhood Services, the Office of Resilience and Racial Equity, the Boston Planning and Development Agency, the Inspectional Services Department, and the Department of Neighborhood Development. The consortium should partner with a broad range of resilience-focused nonprofits, business groups, local community development corporations, local small businesses, and other community-based organizations.

The consortium can act as a coordinating committee for all outreach related to Climate Ready Boston. The consortium should perform two functions. First, it should coordinate both the independent citywide education campaign and the more targeted campaigns that will be undertaken for specific groups, including property owners (see Initiative 2-2, p.90), small businesses (see Initiative 2-3, p.92), and facilities serving vulnerable populations. For example, the Office of Emergency Management runs the "Ready Boston" community preparedness campaign that takes an all-hazards approach (natural or manmade) to informing the public about the risks that they face and what they can do to protect themselves. Second, the consortium will identify opportunities to integrate resilience into existing education campaigns. Across both of these functions, the consortium will ensure integrated and coordinated messaging.

In the short term, the consortium can lead the development of print and online materials in multiple languages and coordinate in-person and social media outreach. The materials should summarize the key findings from Climate Ready Boston, focusing on Boston's three major climate hazards: coastal and riverine flooding, stormwater flooding, and extreme heat. The materials should clearly explain the risks that Boston faces, the time frames over which the city faces them, and the

DIGITAL EQUITY AND ENGAGEMENT

High-speed Internet infrastructure is a tool that all Bostonians need to engage in the educational, economic, and civic pursuits that are critical to a future of equity and opportunity. The City is committed to providing Bostonians with access to high-speed Internet, along with the skills and tools to leverage this technology, to build the individual, family, and community capacity necessary for preparedness. To this end, the City is taking the following steps to support digital equity and engagement:

- The City is expanding the availability of high-speed Internet in places where Bostonians work, learn, play, and engage in civic life, including Boston Public Library branches, Boston Centers for Youth and Families, Boston Public Schools, Main Streets districts, and other important public gathering places.
- The City is working to ensure that community members and local businesses are equipped with the digital tools and skills that they need to take advantage of opportunities and create the future of Boston. City agencies and local nonprofit organizations, such as Tech Goes Home, are collaborating to offer one-time and ongoing digital-skills training, such as basic computer and Internet use, coding, and media production.
- The City is working to support a more competitive broadband marketplace so that households and businesses can choose among a range of high-quality, affordable high-speed Internet options. The City is facilitating collaboration across departments to streamline permitting for broadband infrastructure, support innovative technology during the design and construction of Boston's built environment, and remove building-level barriers to broadband access and choice.

potential impacts of those risks on Boston's people, property, infrastructure, and economy. In the long term, the campaign should seek to increase both the emergency and long-term preparedness of Bostonians, both by building out a network of climate readiness volunteers and preparing Bostonians to engage district-scale climate adaptation planning through Resilience Area Planning Committees (see Initiative 4-2, p.102).

To build out a network of climate-readiness volunteers, the City can tap into the existing Boston Medical Reserve Company (BMRC). BMRC is a citywide volunteer group that receives funding through the U.S. Department of Health and Human Services and is coordinated by the Boston Public Health Commission's Office of Public Health Preparedness. It trains both medical and nonmedical community members in emergency and long-term preparedness. Climate-readiness volunteers can help support both **on-the-ground responses to acute events**, such as assisting neighbors during heat waves and proactively reporting stormwater flooding in their communities, and **longer-term adaptation**—for example, by helping care for young trees to expand the urban canopy.

INITIATIVE 2-2. LAUNCH A CLIMATE READY BUILDINGS EDUCATION PROGRAM FOR PROPERTY OWNERS AND USERS

The City should develop and run a Climate Ready Buildings Education Program to inform property owners and other groups about current and future climate risks facing their buildings and actions they can undertake to increase their preparedness. This education program will be connected to, but also distinct from, the citywide education campaign because of its specific focus on building readiness. It should be linked to building audit and retrofit financing programs (see Initiative 10-1, p.138).

While the Climate Ready Buildings Education Program will focus on property owners, it also will include outreach to three other groups who play a critical role in the use or upgrading of Boston's building stock:

- Tenants, given that the majority of Boston residents are renters and they have the capacity to advocate for resilience upgrades;
- Developers with projects in the pipeline; and
- Design, construction, and property management professionals required for the construction or retrofitting of resilient buildings.

PROPERTY OWNER TYPE	TOUCHPOINT
Large commercial property owners	Their participation in industry groups (e.g., NAIOP Commercial Real Estate Development Association, Greater Boston Real Estate Board, A Better City, and Urban Land Institute).
Market-rate multifamily residential owners	Required registration of their rental property through **DND**. Their participation in industry groups.
Affordable multifamily residential owners	Their application for housing development or rehabilitation financing from **DND**. Their coordination with community development corporations.
Owner-occupants, especially low-to moderate-income owner-occupants	Their participation in homeownership counseling or application for rehabilitation financing through **DND's Boston Home Center and in partnership with local CDCs.**
Owners of small business space	Their application for capital upgrade assistance through Main Streets program.

The Climate Ready Buildings Education campaign should be led by the Boston Planning and Development Agency, the Inspectional Services Department, and the Department of Neighborhood Development (DND). These entities can do outreach to property owners at key touchpoints. For all owners, these points include when they seek development approvals and permits from the Boston Planning and Development Authority and Inspectional Services Department and when they are subject to code enforcement from the Inspectional Services Department. In addition, the City should use outreach to property owners conducted as part of Boston's Community Rating System application (see Initiative 11-2, p.145). Finally, some additional touchpoints by specific owner type are summarized in the table.

The campaign should share print and online resources and potentially include in-person workshops with property owners and other stakeholders. The purpose of the campaign is to build a prepared community of building owners and users across Boston, recognizing the need for broad awareness, because owners and tenants turn over relatively quickly in Boston. The campaign should perform the following functions:

- Educate stakeholders about buildings at risk from climate change hazards over different time periods, taking into account both direct impacts to buildings and indirect impacts to supporting services.
- Inform building owners about the timing and severity of their exposure and the risk levels to which they should be planning. Ideally, this would involve providing owners with information about not only flood depths but also wave heights and moving-water hazards, and also the effects of heat, because these factors affect appropriate adaptation strategies.

SUPPORTING INDIVIDUAL FINANCIAL PREPAREDNESS

The out-of-pocket costs associated with an acute event, such as coastal flooding that temporarily displaces residents from their homes and prevents them from accessing nonsalaried jobs, can be a significant stress for low- and moderate-income households. Today, 46 percent of Boston's residents are liquid-asset poor, meaning that they do not have enough savings to live above the poverty level for three months if they suffer an income disruption such as losing a job.

For this reason, the City should continue to support low-income households in both saving for emergencies and doing long-term asset building through the efforts of the Office of Financial Empowerment (OFE). For example, as one tool to build preparedness, OFE can continue to promote use of myRA federal savings accounts to residents during its financial counseling, financial-literary education, and tax preparation assistance sessions. The myRA program offers free retirement savings accounts to households without access to an Individual Roth Account (IRA) or 401(k) account who make less than $191,000 per year. While deposited funds can be withdrawn from accounts at any time without penalty, accrued interest can only be withdrawn once the account holder reaches the age of 59. By enabling Bostonians to save for retirement but also be able to access funds in the event of an emergency, myRA accounts can potentially serve as a useful tool to advance preparedness goals.

Source: "Financial Insecurity in Boston: A Data Profile," Family Assets Count.

EXISTING PARTNERSHIPS WITH PROPERTY OWNERS

The City can leverage its existing experience working with property owners to educate them about climate change mitigation and adaptation challenges. Since November 2013, the Boston Planning and Development Authority has required all development projects subject to Article 80 large project review (50,000 square feet and over) to analyze and describe their climate preparedness.

- Inform building owners about the need to make both operational changes (e.g., developing continuity of operations and evacuation plans and securing adequate insurance) and physical upgrades to improve resilience. In addition,
- Inform building owners about opportunities to combine climate mitigation and adaptation by making energy-efficiency improvements to their buildings. This may include solar power generation or design elements such as high-

OUTREACH THROUGH PROACTIVE CODE ENFORCEMENT

The City should conduct outreach to private property owners about two relatively inexpensive actions that can reduce their flooding risk.

- **Installation and maintenance of backflow preventers:** The Massachusetts Uniform State Plumbing Code requires backflow preventers to be installed for all buildings with plumbing fixtures located below the manhole cover serving the building (i.e., with any kind of water connection below street level). These preventers stop contaminated sewage from flowing back into a building's systems during sewage overflow events. However, current compliance rates for both installation and maintenance are estimated to be low.
- **Installation and maintenance of tide gates on private storm drain outfalls:** BWSC controls the majority of public storm drain outfalls in Boston, but does not control private storm drain outfalls that run from private properties to the ocean or other waterways, such as the Charles River, Neponset River, and Fort Point Channel. BWSC estimates that there are approximately 1,000 private outfalls in Boston. They have completed mapping of all private outfalls along Fort Point Channel, although other outfalls still need to be identified through fieldwork done at low tide. With sea level rise, outfalls that lie at low elevations along waterways subject to tidal influence will need to be tide-gated to prevent them from backing up and flooding the buildings or sites that they serve.

reflectance "cool roofs" that can reduce property owners' cooling costs while also reducing the urban heat island effect.

- Educate building owners about how they can participate in district-scale adaptation planning efforts, including larger-scale flood defenses that potentially could reduce the need for individual defenses, while also providing education about site-specific mitigation to support multiple layers of protection.

INITIATIVE 2-3. CONDUCT OUTREACH TO FACILITIES THAT SERVE VULNERABLE POPULATIONS TO SUPPORT PREPAREDNESS AND ADAPTATION

As a separate effort, but closely linked to its Climate Ready Buildings campaign, the City should conduct outreach to owners and operators of privately owned facilities that serve significant concentrations of vulnerable populations but that are not currently required to have operational preparedness and evacuation plans under state and local regulations. The purpose of this outreach should be to encourage the owners and operators of these facilities to develop operational preparedness and evacuation plans for situations in which sheltering in place is not feasible, as well as to make needed capital upgrades.

Under current regulations, municipal facilities and healthcare facilities (hospitals, healthcare clinics, and nursing homes) licensed by the Massachusetts Bureau of Healthcare Quality are already required to have operational preparedness and evacuation plans. The City can work with local community development corporations to identify facilities for outreach, with target facilities likely to include privately owned affordable housing complexes, substance abuse treatment centers, daycare facilities, food pantries, small nonprofit offices, and others. The City should encourage facility managers to use planning resources provided by the Federal Emergency Management Agency to develop continuity of operations plans. The City should also prioritize these facilities for climate resilience audits (see Initiative 10-1, p.138) and backup power installation (see Initiative 10-3, p.143).

INITIATIVE 2-4. UPDATE THE CITY'S HEAT EMERGENCY ACTION PLAN

Because the frequency and intensity of heat waves are expected to increase with climate change, the City should continue its efforts to update its heat emergency action plan to reflect both current and likely future needs. The City's action plan lies within the City's Emergency Operations Plan Annex on Extreme Temperatures.

The revised action plan should enhance the framework for coordination during heat events across the City, state agencies, and nonprofit partners critical to preparedness and response. Key state agencies include the Department of Conservation and Recreation, which owns and operates public pools, and the Massachusetts Bay Transit Authority, which operates THE RIDE fleet. The revised plan should ensure that there is a clear set of roles and responsibilities for each partner and define the actions to be undertaken under both heat advisory and heat emergency conditions. In addition, the plan should set a clear set of protocols for the City and its partners to communicate with Bostonians about heat risks across a broad range of channels, including phone, radio, print, online, social media, and in-person outreach.

In addition, in the revised plan, the City should standardize its definitions for both heat advisory and heat emergency events. The Elderly Commission defines a heat emergency as three consecutive days with maximum temperature exceeding 86 degrees Fahrenheit and relative humidity exceeding 68 percent, and a heat advisory when these conditions are in effect for one or two days. The Mayor's Office currently defines a heat emergency as three or more days with maximum temperature exceeding 90 degrees Fahrenheit.

In standardizing its definitions, the City should recognize that different thresholds for taking action to address heat risks may be appropriate for different populations.

In addition, the City should partner with community nonprofits to expand access to facilities with cooling capacity in areas that currently have limited access to municipally owned emergency shelter facilities or that have access only to pool facilities, which are not suitable for the elderly, medically ill, or small children. The City should prioritize installation of backup power at shelter facilities to reduce their risk of losing cooling capacity during heat waves (see Initiative 10-2, p.142). The City also should refine its existing systems to provide transportation to facilities with cooling capacity for older adults and disabled people, with these systems including using the Elderly Commission's Senior Shuttles and MBTA's THE RIDE fleet. The City should partner with community nonprofits and healthcare providers to help disabled residents who lack cooling capacity in their homes register for THE RIDE, if interested, in advance of heat events. In addition, the City should work with the MBTA to reduce the time required for reservations during heat emergencies so that the reservation period is not a barrier to usage.

The City may need to partner with the MBTA to identify additional resources to support this type of service. To serve physically homebound people who cannot leave their homes without assistance, the City should work to help them obtain energy-efficient air conditioners or other means of cooling.

To take advantage of the important role that strong peer-to-peer relationships and community ties play in reducing negative health impacts during heat waves, the City should make heat a major focus of its citywide education and engagement campaign (see Initiative 2-1, p. 88). Communications should help Bostonians understand heat health risks, heat illness symptoms, cooling center locations and hours, and available transportation and emergency services. In addition, as part of its citywide campaign, the City should work to establish a network of neighborhood-level volunteers who can check on socially vulnerable populations, such as seniors, the disabled, and the homeless, during heat waves. The City can leverage existing volunteer networks, such as the Boston Medical Reserve Company, and community nonprofits to help build out these networks. In addition, as part of its outreach to owners and operators of facilities serving concentrations of vulnerable populations, the City should encourage them to educate their clients about heat risks (see Initiative 2-3, p.92). The City can encourage nutrition vendors, home care agencies, and visiting nurses to increase phone and in-person check-ins during heat events.

Finally, the City should work with its partners (state agencies and nonprofits) to improve tracking of the need for public heat support services in Boston to evaluate if services are keeping pace with demand. These metrics include emergency shelter usage, transportation requests, and healthcare service requests. Under a separate set of initiatives (see Strategy 6, p.118), the City will prioritize green infrastructure development in areas that are subject to the urban heat island effect and have high levels of air pollution and socially vulnerable populations.

INITIATIVE 2-5. EXPAND BOSTON'S SMALL BUSINESS PREPAREDNESS PROGRAM

Small businesses play a critical role in employing Boston residents and driving the Boston economy, with 44 percent of Boston's employees in private, for-profit businesses working in small businesses.[1] Because small businesses face challenges in preparing for and recovering from climate change impacts, the City should launch a preparedness program to increase their readiness. The City should leverage the strong existing relationships that it has with small businesses through its Main Streets and Renew Boston Small Business programs to launch Small Business Preparedness Program. The program should be targeted towards small businesses that are exposed to coastal and riverine or stormwater flooding in the near term, because of the potential for physical damage, focusing particularly on Main Streets districts that are exposed under these conditions. The program also should provide information on heat risks.

As part of this effort, the City can facilitate in-person workshops to help small business owners increase their preparedness in five ways:

- Better understand their risks from climate hazards, including coastal and stormwater flooding and extreme heat.
- Develop business continuity plans.
- Evaluate whether they have adequate insurance coverage.
- If they own their space, prioritize necessary physical upgrades for their specific building.
- If they do not own their space, communicate the importance of resilience improvements to property owners.

As needed, the City should partner with the insurance community in Boston to address barriers to insurance coverage to small businesses. The City is undertaking a separate set of initiatives to address insurance availability and cost under Strategy 11 (see p.145). Finally, the City should help connect small business owners and, as relevant, their landlords with the resilience audit program (see Initiative 10-1, p.138). Because cost is a major barrier to making resilience improvements, the City should investigate funding models for building-level resilience improvements under Initiative 10-4 (see p.143).

[1]Source: "Small Business Plan," City of Boston

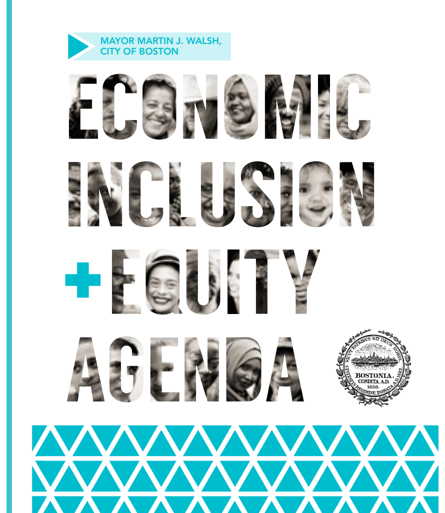
Strategy 3: Leverage climate adaptation as a tool for economic development

INITIATIVE 3-1. IDENTIFY RESILIENCE-FOCUSED WORKFORCE-DEVELOPMENT PATHWAYS

The Office of Workforce Development can explore developing required skill profiles for resilience-focused jobs at a range of skill levels, based on Boston's planned resilience initiatives. For example, potential resilience-focused jobs may include performing resilience audits of buildings and installing and maintaining green infrastructure. To prepare Bostonians for these jobs and create a pipeline of local workers prepared to undertake resilience projects, the Office of Workforce Development then should create a plan to incorporate resilience skills development into Boston's existing job-training programs and establish resilience-focused workforce-development pathways. The Office of Workforce Development also should work to incorporate resilience retrofit skills training into its existing construction pre-apprenticeship and apprenticeship training programs.

INITIATIVE 3-2. PURSUE INCLUSIVE HIRING AND LIVING WAGES FOR RESILIENCE PROJECTS

The City can consider the hiring of graduates of Boston's resilience workforce-development programs for firms working on resilience projects that receive City funding or land. In addition, the City can explore whether City-sponsored resilience projects can pay employees a prevailing or a living wage to support economic opportunity for all Bostonians. Under the initiatives set out in Imagine Boston 2030, the City is advocating for a higher minimum wage to improve economic mobility for Boston workers and help ensure that all Boston residents are able to earn a family-sustaining wage.



USING CLIMATE INVESTMENTS TO ADVANCE EQUITYEQUITY

In the coming years, the public, private, and nonprofit sectors will be making large investments in climate mitigation and adaptation. Earlier this year, the City released its Economic Inclusion and Equity Agenda, which provides a detailed overview of the City's ongoing programs, policies, and initiatives to address racial and economic disparities in Boston. The agenda provides context for the City's work across four themes: income and employment, wealth creation, business development, and economic mobility. To fulfill its commitment to inclusive growth, the City should undertake the initiatives under Strategy 3 to ensure that these investments yield maximum benefits to residents in terms of job creation, workforce development, and entrepreneurship opportunities.

BOSTON'S EXISTING RESIDENT JOB POLICY

City agencies should leverage the existing Boston Resident Job Policy to increase resident employment on City-sponsored development projects and support equity in hiring and contracting. Under this policy, developers and contractors agree to make best-faith efforts to employ 50 percent residents, 25 percent people of color, and 10 percent women across all trades.

Climate Ready Boston / Boston Harbor Now Workshop

INITIATIVE 3-3. PRIORITIZE USE OF MINORITY- AND WOMEN-OWNED BUSINESSES FOR RESILIENCE PROJECTS

The City can request that City-sponsored resilience projects prioritize minority and women-owned businesses for spending on capital and operating and maintenance costs. The Mayor's 2016 Executive Order on Procurement set spending goals for minority and women-owned business enterprises (MBE and WBE, respectively) competing for City construction, architecture, engineering, and professional services contracts.[2] The spending goals, which range from 10 to 25 percent MBE and 15 to 20 percent WBE utilization, depending on the type and size of the contracts, can be applied to all City-sponsored resilience projects.

[2] "An Interim Executive Order Promoting Equity in Public Procurement." Executive Order of Mayor Martin J. Walsh, 2016.

MAIN STREETS PREPAREDNESS PROGRAM MODELS

For the Main Streets Preparedness Program, the City can draw on precedents from both within and outside the Boston metro. The Metropolitan Area Planning Commission has been working with the City of Cambridge to assist Cambridge's small businesses in recovering quickly from business disruption. New York City's Business Preparedness and Resiliency Program (BPREP) offers resilience planning workshops, building assessments, grants for building retrofits, and online tools for assessing vulnerability and potential adaptation strategies.

Source:"Business Preparedness and Resiliency Program (PREP)." The City of New York.

EMERGENCY SHELTERS

The City and community organizations currently operate many facilities throughout Boston that offer cooling capacity during heat waves. The City will work with community organizations to ensure that these facilities are open whenever necessary, accessible to all who need them, and feature backup power in case of power outages.

BOSTON'S EXISTING WORKFORCE-DEVELOPMENT PROGRAMS

The Office of Workforce Development can leverage a number of existing workforce-development programs to explore providing the infrastructure for climate resilience-focused job training. In particular, the Office of Workforce Development can use the framework of the Greater Boston American Apprenticeship Initiative, which includes the Building Pathways and YouthBuild programs, to offer construction pre-apprenticeship and apprenticeship opportunities. The Greater Boston Apprenticeship Initiative was launched in the fall of 2015 with a U.S. Department of Labor grant. Building Pathways is a six-week pre-apprenticeship program run by the Metropolitan Boston Building and Construction Trades Council that provides women and people of color with an introduction to careers in the building trades, gives them the opportunity to earn key certifications, and provides them with guaranteed placement into an apprenticeship program. YouthBuild Boston is a 12-week pre-apprenticeship program to youth ages 14–24 that offers them the opportunity to earn key certifications in preparation for building trades apprenticeships. The Office of Workforce Development also can explore incorporating resilience skills development into the Mayor's Youth Summer Jobs Program and Operation Exit, an intensive career-readiness and occupational skills training program that prepares at-risk youth and young adults for buildings trades apprenticeships.

PRECEDENT: CITY OF NEW ORLEANS WORKFORCE-DEVELOPMENT PROGRAM

In recent years, New Orleans has become a national leader in resilience workforce development, and is poised to extend this role through its winning project under the U.S. Department of Housing and Urban Development's National Disaster Resilience Competition, "Reshaping the Urban Delta." New Orleans's program offers several useful best practices for Boston:

- Defining short-term and long-term workforce-development objectives. New Orleans has committed to both train unemployed and underemployed working-age individuals for job readiness in the short term and develop the next generation of design and construction professionals in the long term. It has set a target that over 10 percent of resilience project jobs will be filled by unemployed or underemployed individuals.
- Developing a clear set of workforce-development pathways. New Orleans has prioritized environmental services and water-management-sector workforce development. It has elected to focus on these sectors because they have both local demand and export potential.
- Incentivizing firms to exceed workforce-development targets. When bidding out contracts, New Orleans encourage respondents to exceed Section 3 training and hiring requirements for low- or very-low-income residents by making the additional costs incurred to provide extra training eligible for reimbursement as long as they are deemed reasonable.
- Supporting workforce-development accountability. New Orleans has implemented a rigorous tracking system to ensure that workforce-development graduates hired by contractors are receiving pledged training and employment opportunities.

Source:"City of New Orleans Application to HUD National Disaster Resilience Competition." City of New Orleans, 2015.

Layer 3

PROTECTED SHORES

Strategy 4: Develop local climate resilience plans to coordinate adaptation efforts

INITIATIVE 4-1. DEVELOP LOCAL CLIMATE RESILIENCE PLANS TO SUPPORT DISTRICT-SCALE CLIMATE ADAPTATION

The City should develop local climate resilience plans to address climate adaptation in areas of geographically concentrated climate risks. The priority local climate resilience plans should be for East Boston, Downtown, Charlestown, South Boston, and Dorchester, which face the greatest risk from coastal flooding in the near term. For these and subsequent local climate resilience plans, all climate hazards should be addressed, including coastal and riverine flooding, extreme heat, and stormwater flooding.

Local climate resilience plans should coordinate all climate adaptation efforts within a district. This would allow the City and its partners to use limited resources more wisely and avoid the duplication of investments, not only in capital projects but also in planning, design, and operations. District coordination also offers opportunities for the City or its partners to capture some or all of the value created by climate readiness efforts in order to finance these investments and to integrate other community priorities—such as housing affordability, economic opportunity, access to quality open space, and safe and efficient mobility—in tandem with climate adaptation. At the district scale, climate readiness efforts can be integrated with locally specific initiatives to advance multiple goals simultaneously.

The local climate resilience plans should include the following:

- **Community Engagement** (see Initiative 4-2, p.102). To understand current challenges facing residents, businesses, and institutions and to develop creative solutions to address these challenges, the City should work with district stakeholders through local climate resilience committees. Representative of their neighborhoods, these committees should gather data, provide input on potential resilience actions, and identify potential co-benefits of climate adaptation such as increased access to economic opportunity for an improved public realm. Engagement with the local climate resilience committees should be a feature of all components of local climate resilience plans.
- **Land Use Planning for Future Flood Protection Systems** (see Initiative 5-1, p. 106). To support the feasibility of district-scale flood protection systems, the Boston Planning and Development Agency should establish Flood Protection Overlay Districts in strategically important "breach points" where floodwaters can enter and inundate large inland areas. New development proposals at these breach points would need to demonstrate the potential for integration into future flood protection systems. This is particularly important in areas where waterfront development is currently proceeding rapidly and may introduce new challenges for the creation of future flood protection infrastructure.
- **Flood Protection Feasibility Studies** (see Initiatives 5-2, 5-3, pp. 106, 110). The City should apply a consistent framework for evaluating the feasibility of district-scale flood protection alternatives. Key considerations include flood risk reduction benefits; additional benefits like recreation or economic development; environmental impacts; cost; land ownership; permitting; and intergovernmental coordination.
- **Infrastructure Adaptation Planning** (see Initiative 6-1, p.118). The City should work with the Infrastructure Coordination Committee to develop district-scale infrastructure adaptation plans to prepare existing infrastructure—and design new infrastructure—for climate change. This may include opportunities for joint capital planning, such as the elevation of a road combined with upgrades to the stormwater management system or coordination with district-scale flood protection infrastructure.
- **Coordination with Other Plans** (see Initiative 9-5, p.138). The City should coordinate with other planning processes such as Imagine Boston 2030, 100 Resilient Cities, Special Planning Areas, or Municipal Harbor Plans to ensure that district-scale climate adaptation is incorporated into area plans and, where appropriate, codified into the Zoning Code.
- **Development of Financing Strategies.** The City should evaluate and, as necessary, provide implementation support for financing strategies to support district-scale adaptation. The strategies may include federal and state infrastructure funds, special assessment districts, resilience business improvement districts or joint capital planning structures to collect funds from the beneficiaries of adaptation projects. Assessment districts could help the City to fund capital and operating expenses for district-scale resilience investments by levying a small tax on the properties that benefit. Joint capital planning among agencies and other actors could enable larger-scale interventions that reduce the need for individual interventions and pool resources from the agencies that benefit from the large-scale interventions.
- **Development of Governance Structures.** The City should evaluate and, as necessary, provide implementation support for governance structures for managing the implementation, operations, and maintenance of adaptation actions. These governance structures may include formation of a special assessment district governing board, resilience business improvement district, or public-private partnership. The form of the governance structures should be guided by the type and financing needs of resilience actions to be undertaken.

LOCAL CLIMATE RESILIENCE PLANS FOR DISTRICT-SCALE ADAPTATION

The City should develop local climate resilience plans for East Boston, Downtown, Charlestown, South Boston, and Dorchester, which face the greatest risk of geographically concentrated coastal flooding. For these and subsequent local climate resilience plans, all climate hazards should be addressed, including coastal and riverine flooding, extreme heat, and stormwater flooding, as should additional community priorities.

PRECEDENT: CLIMATE CARE COMMUNITY PARTICIPATION MODEL

The Climate CARE (Community Action for Resilience through Engagement) program in East Boston is being led by the Neighborhood of Affordable Housing (NOAH), with funding from the Kresge Foundation. The program consists of two major components. First, it employs local residents as "Climate Canvassers" to educate East Boston residents about current and future climate risks in a multiyear outreach effort. Second, it brings together local residents, public-sector entities conducting adaptation planning, and planning, design, and engineering experts in working groups to discuss community input and priorities, with the goal of developing a set of pilot design projects. Climate CARE builds on earlier work done by NOAH and the University of Massachusetts-Boston and the University of New Hampshire, with funding from the National Oceanic and Atmospheric Administration. NOAH and its partners held workshops in May and June 2014 to map key assets and generate preliminary adaptation strategies, including a set of multipurpose flood barriers.

INITIATIVE 4-2. ESTABLISH LOCAL CLIMATE RESILIENCE COMMITTEES TO SERVE AS LONG-TERM COMMUNITY PARTNERS FOR CLIMATE ADAPTATION

The City should work with local residents, businesses, and institutions in each resilience planning area to form a local climate resilience committee to help guide district-scale climate adaptation activities (see Initiative 4-1, p.100). The committees should help identify local challenges and develop creative solutions, ensure that other local initiatives—such as economic development or open space planning—are integrated with climate adaptation, and steward the ongoing adaptation process over time.

Local climate resilience committees may take a variety of forms and may have multiple missions depending on the needs of each neighborhood and other planning and development initiatives. A committee may be staffed by a community-based organization with a long-term presence in the area and the capacity to work productively with local residents and public agencies. The committees should help to disseminate information about climate-related risks and gather feedback on local residents' priorities for climate adaptation. The development of these local climate resilience committees should fit within Greenovate's existing efforts to establish a climate action network.

Strategy 5: Create a coastal protection system

As discussed in the Climate Ready Boston Vulnerability Assessment, Boston faces significant and increasing coastal flood risk due to a combination of sea level rise, high tides, and coastal storm events. A key component of the multilayered strategy for addressing this risk is to create a robust system of coastal protection infrastructure that responds to community needs and ecological dynamics.

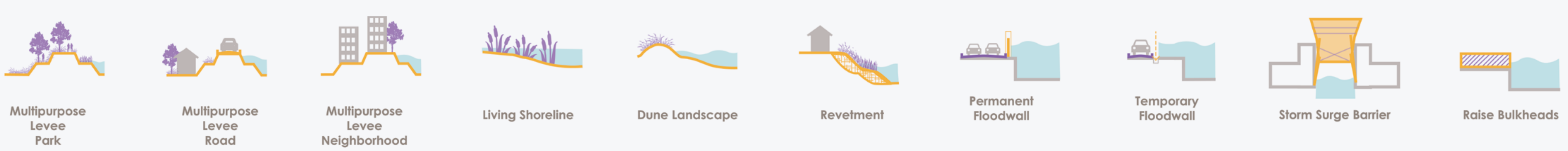
There are generally three **categories of coastal protection:**

1. **"Gray," or hard-engineered coastal infrastructure,** such as levees, floodwalls, or gates. Typically, gray coastal infrastructure is necessary to protect built-up areas from severe flood events like coastal storms, as it is designed to be strong enough to withstand coastal forces and high enough to reduce risk from storm surge.
2. **"Green," or nature-based, coastal infrastructure,** such as wetlands or living shorelines. Green coastal infrastructure alone is typically most appropriate for protecting against chronic flooding events like future high tide or minor storms, rather than severe coastal storm events. This is because it is

SUMMARY OF INITIATIVES TO CREATE A COASTAL PROTECTION SYSTEM

#	INITIATIVE	SUMMARY
5-1	Establish Flood Protection Overlay Districts and require potential integration with flood protection	Based on preliminary hydrological analyses, establish new overlay districts in potential flood protection system locations and require that development proposals do not prevent the future creation of flood protection infrastructure.
5-2	Determine a consistent evaluation framework for flood protection system prioritization	Determine a framework through which alternative flood protection systems would be consistently evaluated, and which is compatible with the framework used by the U.S. Army Corps of Engineers, a key implementation and funding partner.
5-3	Prioritize and study the feasibility of district-scale flood protection	Using a consistent evaluation framework (Initiative 5-2), study the feasibility of district-scale flood protection in a number of locations, prioritizing those that face the greatest risk.
5-4	Launch a feasibility study of a harbor-wide flood protection system	Using a consistent evaluation framework (Initiative 5-2), study the feasibility of a Harbor-wideharbor-wide flood protection system.

EXAMPLE FLOOD PROTECTION DESIGNS



unlikely to reach the elevation necessary to sufficiently reduce storm surge, even if it does dissipate wave energy and slow-moving water.

Green coastal infrastructure may feature certain advantages over gray coastal infrastructure in terms of ecological benefits, long-term adaptability, and lifetime maintenance costs. However, it can be particularly challenging to site in urban areas, since it generally has a much broader footprint than gray infrastructure and requires specific environmental conditions that foster ecological function and habitat suitability.

3. **Hybrid coastal infrastructure,** which incorporates both "gray" and "green" components. Examples of hybrid infrastructure include reinforced dunes or living shorelines that contain engineered levees. These infrastructure types are designed to withstand coastal forces and storm surge during extreme events and may provide some of the benefits of green coastal infrastructure, with similar challenges for finding appropriate sites.

There are two **scales** of coastal protection that are possible for Boston:

1. **District-scale coastal protection.** These are infrastructure investments at or near the waterfront that can reduce flood risk for a specific area within Boston. In each case, some type of flood barrier would need to be constructed, connecting two points of high ground in order to reduce flood risk in low-lying areas. Generally, these defenses would be more cost effective in narrow low-lying areas where floodwaters can enter and inundate large inland areas and less cost-effective in broad, low-lying exposed areas.

2. **Harbor-wide coastal protection.** These are offshore interventions in Boston Harbor that can reduce flood risk for all of Boston, as well as neighboring cities. These interventions could be used to achieve two outcomes:

    - Decreasing Boston Harbor's tidal range. Boston Harbor's tidal range could be lessened by narrowing or shallowing the inlets between Harbor Islands. Reducing the openings between islands acts to reduce the exchange of water and moderate the tidal range. This would effectively lower the high tide (and raise the low tide) in the harbor, reducing tidal inundation as well as storm surge inundation.
    - Blocking storm surge. Boston could be protected from storm surge by installing a system with operable gates that could be temporarily closed during storm events to prevent storm surge from penetrating into Boston Harbor from the North Atlantic.

There may be potential solutions that would decrease Boston Harbor's tidal range without including an operable gate to block storm surge. However, since any operable surge barrier would require construction in the harbor, such a solution would also end up decreasing the tidal range.

See Initiative 5-2 (p. 106) for further discussion of the potential implications of flood protection infrastructure.

Image courtesy of Sasaki

THE MULTIPLE LAYERS APPROACH

Resilient solutions are independently effective (provide benefits on their own) but can also be applied in multiple layers to increase effectiveness. This multiple-layers approach is applied to the flood protection strategy described here, where both district-scale and harbor-wide flood protection plans are advanced simultaneously.

While the pursuit of both district-scale and harbor-wide flood protection may at first seem duplicative, there are a number of reasons to pursue them in parallel:

- Time. The smaller scale of the district-scale interventions means that they would likely be less expensive, complex, and time consuming to implement than a harbor-wide intervention would be. Many Boston neighborhoods face significant coastal flood risk today and would benefit from district-scale interventions as soon as they are implemented. Even if harbor-wide and district-scale interventions were aggressively pursued, there could be a period of years or even decades between when a district solution would be operational and when a harbor-wide solution could be in place.
- Scale. The cost and complexity of a harbor-wide intervention may prevent it from ever being fully implemented.
- Co-Benefits. District-scale flood protection and harbor-wide interventions offer different opportunities for co-benefits, such as parkland, transportation infrastructure, or additional developable land.
- Negative Impacts. While the flood risk reduction benefits of a harbor-wide intervention may be far greater than those of a district-scale intervention, the potential for negative impacts on the regional ecology and economy would also be far greater.
- Risk of Failure. If a harbor-wide intervention were to fail and there were no district-scale flood protection, the results could be catastrophic. At the same time, however, district-scale interventions are also not fail-proof, as they can be overtopped. For this reason, even buildings behind flood protection structures should retrofitted or built to climate-ready standards, and communities should be prepared for severe storms.
- Regular Tidal Inundation. Some areas like South Boston and East Boston will face monthly inundation once sea level rise passes a certain threshold later this century. A harbor-wide intervention alone may not be able to prevent all tidally induced flooding, requiring a multiple-layers approach over the long term.

THE HARBOR ISLANDS AND FLOOD RISK

The Harbor Islands play an important role in mitigating tides and wave action between the Atlantic Ocean and Boston's shores. They slow the rate at which water can enter and exit the harbor, decreasing the difference in elevation between high tide and low tide, and they also dissipate the energy of waves entering the harbor. As sea levels rise, the Harbor Islands are at risk of shrinking. Currently, a team of public and nonprofit partners are studying the erosion of the Islands and the potential for installing submerged breakwaters—including using materials from the U.S. Army Corps of Engineers' dredging of the harbor channels—to act as wave attenuators which would promote shoreline protection and possibly provide habitat for species like eelgrass. The team includes the City of Boston, the U.S. Army Corps of Engineers, the Massachusetts Office of Coastal Zone Management and the Division of Marine Fisheries, The Nature Conservancy, and Northeastern University.

BOSTON'S EXISTING COASTAL PROTECTION STRUCTURES

In addition to flood protection provided by natural waterfront areas such as the Belle Isle Marsh, Boston is already protected by a number of manmade coastal protection structures. The Massachusetts Department of Coastal Zone Management conducted an inventory and assessment of publicly-owned coastal structures in 2015, and identified a total of 110 structures in Boston, with 18 structures in East Boston, 16 in Charlestown, 13 in Downtown Boston, 36 in South Boston, and 27 in Dorchester. Approximately $46 million in rehabilitation funds would be required to bring all structures up to an "A" condition rating, with $23 million of that required for structures that are in "D" or "F" condition. Given that well-maintained structures are necessary to provide effective protection, there is a resilience opportunity associated with restoring and upgrading Boston's existing structures.

INITIATIVE 5-1. ESTABLISH FLOOD PROTECTION OVERLAY DISTRICTS AND REQUIRE POTENTIAL INTEGRATION WITH FLOOD PROTECTION

The Boston Planning and Development Agency (BPDA) should petition the Boston Zoning Commission to create new Flood Protection Overlay Districts in areas that are strategically important for potential future flood protection infrastructure. These areas are low-lying "breach points" near the waterfront where floodwaters could enter neighborhoods and where targeted district-scale interventions could yield significant risk reduction (see Initiative 5-3, p.110). The purposes of the Flood Protection Overlay Districts are first to recognize that the rapid pace of development occurring in strategically important areas today could increase the cost and complexity of potential future district-scale flood protection, and second, to provide a regulatory mechanism to address that situation. Drawing on the findings from the Vulnerability Assessment, and specifically the locations of key inundation points, Climate Ready Boston has identified a set of potential locations for flood protection systems that could address inundation points by connecting places of high ground (see map, "Potential Flood Protection Locations," and the Focus Areas chapter of this report).

Within a Flood Protection Overlay District, a developer would be required to submit a study of how the proposed project could be integrated into a future flood protection system; options may include raising and reinforcing the development site or providing room for a future easement across the site. The BPDA should engage in conversations with the development community to develop guidelines for such studies and determine a minimum project size for this requirement so that small projects are not unnecessarily burdened. Proposals should consider the feasibility of nature-based flood protection systems that may include dunes, landscaped berms, or created salt marshes or oyster reefs.

INITIATIVE 5-2. DETERMINE A CONSISTENT EVALUATION FRAMEWORK FOR FLOOD PROTECTION PRIORITIZATION

The City should establish a framework through which alternative district-scale and harbor-wide flood protection systems would be consistently evaluated. While this framework should be guided by local priorities, it must also be compatible with the framework used by the U.S. Army Corps of Engineers, who would be an indispensable partner on studying, permitting, funding, and implementing any flood protection infrastructure.

It is critical to consistently quantify the social, environmental, and economic benefits of each alternative intervention—with particular attention to social equity and the needs of socially vulnerable populations—so that they can be weighed both against the costs of the project and against each other. Any evaluation framework must compare a baseline "without project" scenario, in which flood risk continues to increase with sea level rise, to "with project" scenarios, in which flood risk is managed through appropriate interventions.

The key considerations for an evaluation framework for district-scale and harbor-wide flood protection systems include: flood risk reduction benefits; additional benefits, such as quality of life impacts; environmental impacts; cost; land ownership; permitting and regulations; and intergovernmental coordination. Each consideration is discussed further below.

- **Flood risk reduction benefits.** The primary goal of a flood protection system is to reduce the flood risk for residents, businesses, property, and infrastructure, ensuring that Boston can continue to thrive as sea levels rise.

  The information in the Climate Ready Boston Vulnerability Assessment is an initial attempt at quantifying flood risk and therefore the potential for risk reduction. For example, there are currently over 90,000 Bostonians and 12,000 buildings in the areas expected to be inundated during a 1 percent annual chance flood event under a 36-inch sea level rise scenario (2070s or later). Under this scenario, the expected economic losses[3] in the City of Boston from such a flood event would be over $14.2 billion. The potential flood risk reduction benefits at specific locations are detailed in the Focus Area chapter.

  These estimates only consider current people and property in Boston, and do not take into account population growth or future development. Further studies should verify the flood risk reduction potential of multiple district-scale and harbor-wide intervention designs, considering Boston's neighbors who also face flood risk from the harbor, as well as future city and regional growth.

  - *Residual flood risk.* The City must consider "residual risk," or the risk remaining after the flood protection system is built. This includes the risk that a flood event of greater magnitude or intensity occurs than the one selected as the basis for design, as well as increased risk due to the diminished drainage capacity of the area behind the flood protection system.

  - *Induced flood risk.* The City must also consider potential impacts on areas outside the flood protection system, which could potentially face greater risk of flooding due to the displacement of water by the flood protection system.

[3]Includes direct physical damage, displacement costs, and stress factors. See Vulnerability Assessment for details.

FINANCING A FLOOD PROTECTION SYSTEM

Through its General Investigation Program, the U.S. Army Corps of Engineers (USACE) helps communities study and construct flood risk management projects. Typical feasibility studies take three years to complete, and cost up to $3 million, with costs split evenly between the federal government and the local sponsor. If the project is found to have federal interest and a favorable benefit-cost ratio, the federal government can fund up to 65 percent of construction costs, with the local sponsor contributing the remainder, as well as all operations and maintenance costs. For the USACE to pursue study and construction through the General Investigation Program, Congress must provide authorization and appropriate funds. The City should work with its senators and congressional representatives to advance this agenda in Congress.

While this federal process can be extremely helpful for advancing flood protection projects, it typically takes years to even begin a feasibility study. Given the urgency of these projects, Boston should advance studies outside of the USACE process—but using a framework that is compatible with USACE methodologies—to both accelerate the timeline of the studies and increase the likelihood that the USACE would eventually get involved. This was the approach taken by six proactive Texas counties around Houston and Galveston, which are currently funding a comprehensive flood protection study using the USACE's process and with the USACE engaged as reviewers. The goal is to reach a consensus with key stakeholders and then pass the study to the USACE, who should be able to use the study findings, model, and data for future phases to save on costs and accelerate the overall study timeline.

Even if there is significant federal financial support for a harbor-wide intervention, Boston and its neighbors would still be required to finance a large portion of the project.

- **Additional benefits.** To maximize both the total benefits of a flood protection system and its potential to generate revenue for its own construction, design alternatives should advance other community goals in addition to flood risk reduction. For example, flood protection systems could be used to create new recreational and ecologically productive open spaces through green coastal infrastructure, new or newly protected land for residential or commercial development, or new transportation infrastructure. There are many existing and proposed examples from around the world of flood protection being incorporated into other investments that improve quality of life in a city. Brooklyn Bridge Park, for example, was built with shoreline riprap, a constructed marsh, and lands elevated well above the floodplain, protecting the park and some inland areas from damage during Hurricane Sandy. These benefits can also help avoid, or mitigate, any negative quality of life impacts. For example, a system that requires the construction of a vertical wall may block physical or visual access to the waterfront; a system that utilizes a landscaped berm would improve waterfront access and opportunities for recreation, education, and tourism.

- **Environmental impacts.** Any flood protection system would have both immediate and lasting impacts on the region's complex ecosystems, including effects on water quality and coastal habitats.

  In assessing environmental impacts, it is crucial to compare them to a baseline "without project" scenario in which there is no harbor-wide intervention and the sea continues to inundate land with increasing frequency. For example, a harbor-wide intervention would likely disturb Belle Isle Marsh, Neponset River, and other intertidal wetlands in the harbor by altering salinity, nutrient, and toxin loads and other biochemical factors. However, without a harbor-wide intervention or adjacent land for these wetlands to migrate to over time, sea level rise will more quickly convert these areas to open water and eliminate the benefits wetlands provide. Because sea level rise will threaten key habit areas with or without flood protection interventions, expected future environmental conditions with and without interventions need to be understood.

  Although district-scale flood protection infrastructure would not have the same scale of environmental impact as a harbor-wide intervention, it would still have consequences for local natural systems. Impacts on ecological systems, such as species habitat, and public health, such as water quality, must be studied. On the other hand, both harbor-wide and district-scale flood defenses would have some near- and long-term ecological benefits that should be further understood. For instance, baseline "without project" scenarios would include uncontrolled flooding in many urban and industrial areas, heightening Boston Harbor's exposure to toxins. By reducing the probability of flooding, harbor-wide and district-scale flood defenses would reduce the probability of toxic releases that would harm harbor ecosystems.

- **Cost.** The planning, design, construction, environmental mitigation, and annual operations and maintenance activities for a coastal protection system would all require significant expenditures.

  Primary cost drivers for solutions such as the harbor-wide intervention would be the large gate structures and marine walls,which would span 1.5 to 3.5 miles and require deep foundations to withstand the forces of storm events.

  For district-scale defenses, cost is affected by flood protection location and typology and the physical and urban conditions of the location where defenses are being built. Cost considerations include the relative size of the flood protection system, its relative complexity (e.g., deployable gates across road intersections make systems much more expensive to build and operate), and opportunities to integrate flood protection with other infrastructure and redevelopment to reduce and share costs.

- **Land ownership.** Flood protection systems will likely span multiple parcels of land. To minimize the cost and complexity of flood protection, public land should be used wherever possible. In order for FEMA to certify a flood protection project, which is necessary for realizing National Flood Insurance Program savings, the project must be publicly owned and maintained. If any private land were incorporated into a project, it would require an easement to allow 24-hour access for maintenance activities. To reduce challenges associated with private ownership, especially fragmented private ownership, public parcels or rights-of-way are preferred wherever possible.

- **Permitting and regulations.** Regulations affect the feasibility of flood protection both directly, by setting the parameters for the permitting process, and indirectly, by controlling the types of uses that can occur near the defenses and therefore the ability to raise funds from nearby properties.

  As with any major water infrastructure project, a number of local, state, and federal agencies would need to approve a coastal protection system.

  At the local level, the Boston Conservation Commission is the agency responsible for reviewing projects impacting wetlands, under the Massachusetts Wetlands Protection Act.

  At the state level, the Office of the Secretary of Energy and Environmental Affairs is responsible for administering the Massachusetts Environmental Policy Act (MEPA), the primary environmental law that governs major actions taken by Massachusetts governments. In addition, the state Department of Environmental Protection administers Chapter 91, the Massachusetts Public Waterfront Act, which includes requirements for public access and water-dependent uses. The MassWildlife Natural Heritage and Endangered Species Program administers the Massachusetts Endangered

FLOOD RISK REDUCTION BENEFITS

As sea levels rise, the potential benefits of a harbor-wide intervention, in terms of avoided impacted people and economic losses, will increase. This table of potential flood risk reduction benefits only includes the current people and property in Boston; the actual avoided losses would be larger because they would include areas outside Boston and because the region's population and economic activity are expected to continue to grow.

	9" SLR (2030s-2050s)	21" SLR (2050s-2100s)	36" SLR (2070s-2100s)
Population exposed to 1 percent annual chance flood	16,000	43,000	90,000
Buildings exposed to 1 percent annual chance flood	2,000	6,000	12,000
Estimated economic losses from a 1 percent annual chance flood	$2.3 billion	$6.2 billion	$14.2 billion

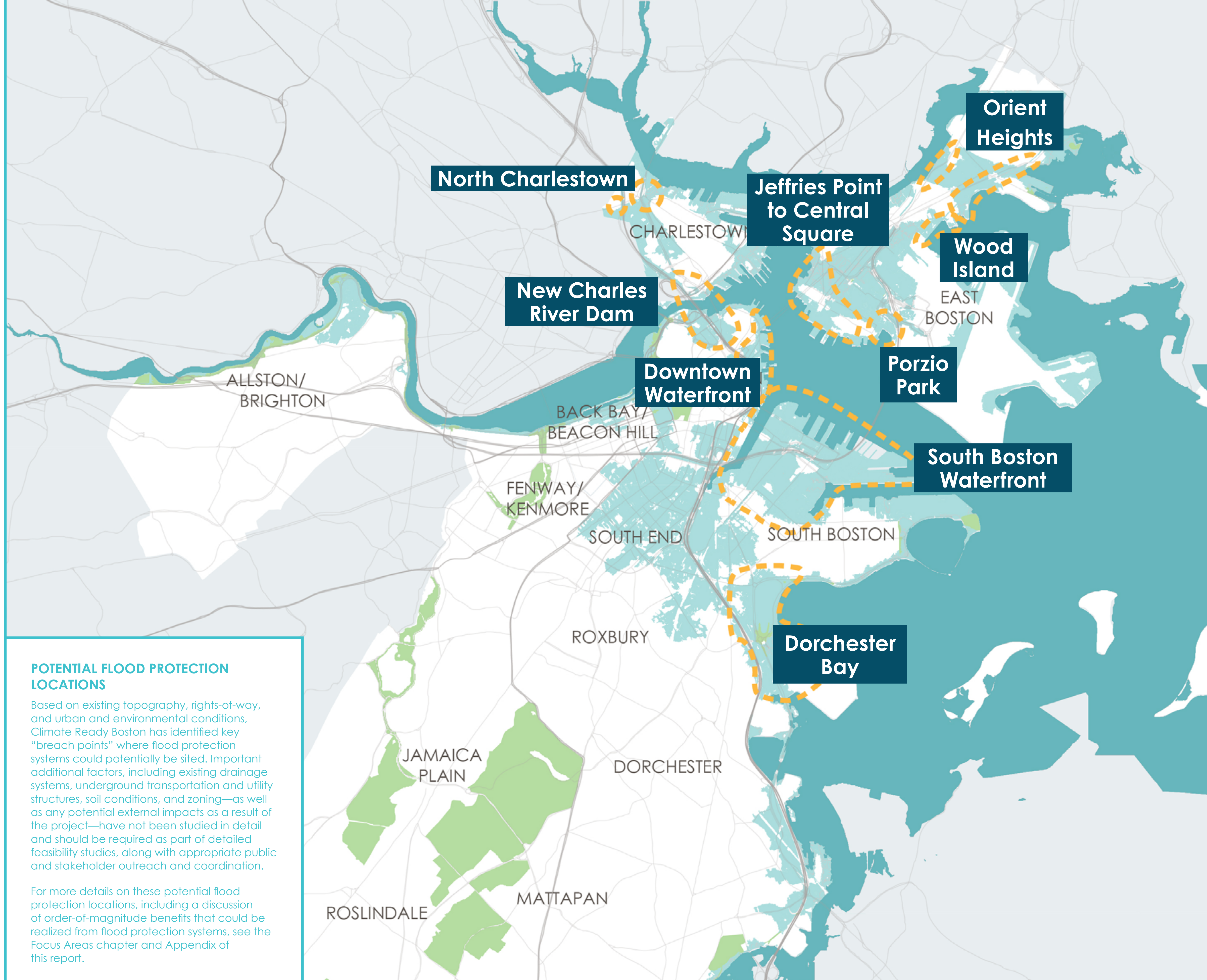
Species Act. Finally, the Massachusetts Office of Coastal Zone Management (CZM) would need to be involved in project review to ensure that the proposed activities are consistent with Massachusetts's enforceable coastal program policies and to conduct a federal consistency review for any project requiring federal permitting or funding.

At the federal level, the U.S. Army Corps of Engineers would likely lead coordination with other federal agencies, including the U.S. Fish and Wildlife Service and the Environmental Protection Agency. Regulators would consider project impacts on the natural environment, historic and cultural resources, and the navigability of Boston Harbor by commercial and recreational vessels.

- **Coordination with other municipalities and government entities.** Harbor-wide and district-scale interventions are likely to require close collaboration with neighboring cities and towns, such as Cambridge, Chelsea, Winthrop, and Quincy, as well as the state and regional agencies.

INITIATIVE 5-3. PRIORITIZE AND STUDY THE FEASIBILITY OF DISTRICT-SCALE FLOOD PROTECTION

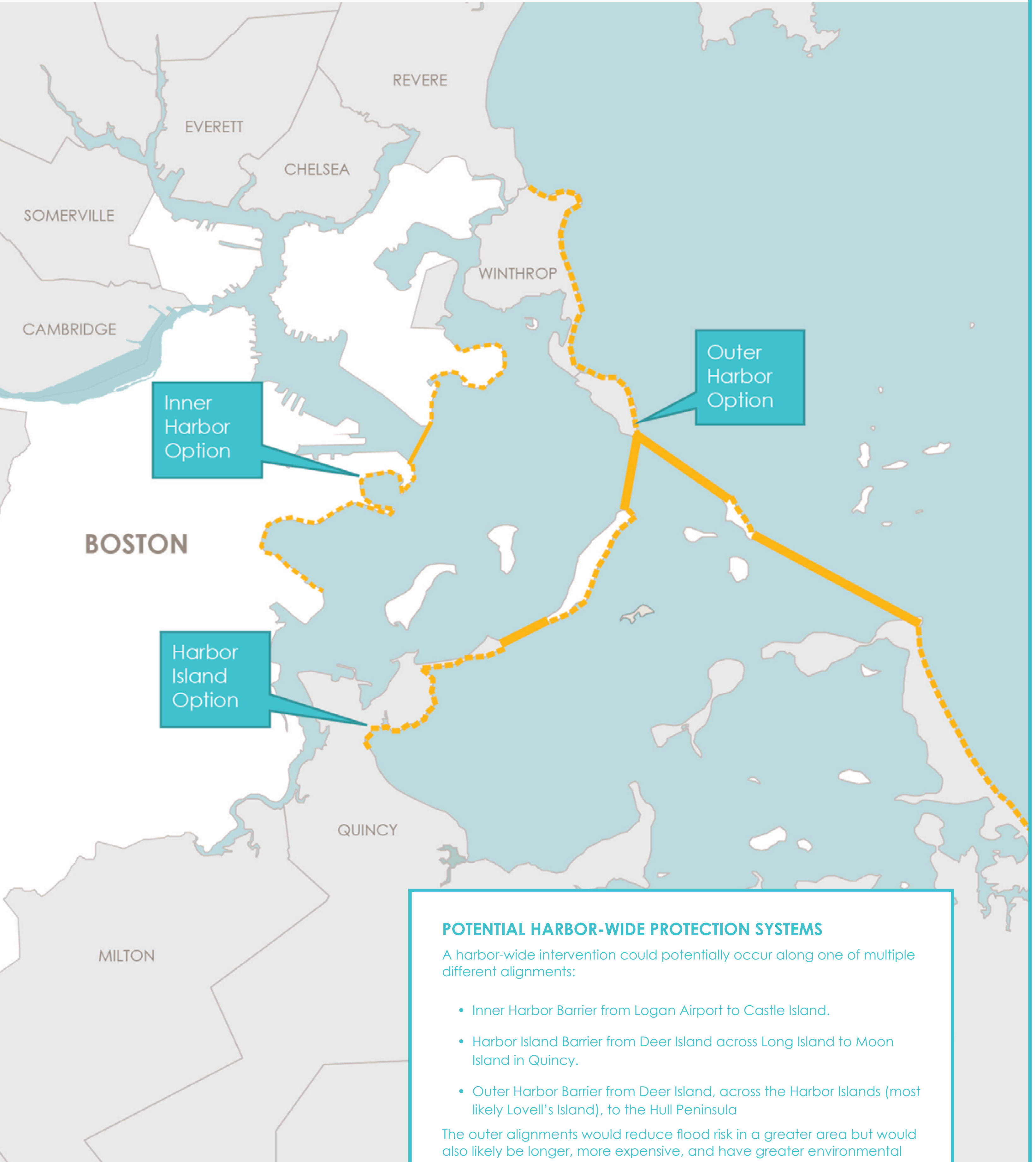
Applying a consistent evaluation framework (see Initiative 5-2, p.106), the City should study the feasibility of district-scale flood protection in a number of locations and prioritize them based on costs and benefits to populations, businesses, property, and infrastructure. For more details on potential flood protection locations, including a discussion of order-of-magnitude benefits that could be realized from each, see the Focus Areas chapter and Appendix of this report. These feasibility studies should take place in the context of local climate resilience plans (see Initiative 4-1, p.100), featuring engagement with local communities, coordination with infrastructure



POTENTIAL FLOOD PROTECTION LOCATIONS

Based on existing topography, rights-of-way, and urban and environmental conditions, Climate Ready Boston has identified key "breach points" where flood protection systems could potentially be sited. Important additional factors, including existing drainage systems, underground transportation and utility structures, soil conditions, and zoning—as well as any potential external impacts as a result of the project—have not been studied in detail and should be required as part of detailed feasibility studies, along with appropriate public and stakeholder outreach and coordination.

For more details on these potential flood protection locations, including a discussion of order-of-magnitude benefits that could be realized from flood protection systems, see the Focus Areas chapter and Appendix of this report.



POTENTIAL HARBOR-WIDE PROTECTION SYSTEMS

A harbor-wide intervention could potentially occur along one of multiple different alignments:

- Inner Harbor Barrier from Logan Airport to Castle Island.
- Harbor Island Barrier from Deer Island across Long Island to Moon Island in Quincy.
- Outer Harbor Barrier from Deer Island, across the Harbor Islands (most likely Lovell's Island), to the Hull Peninsula

The outer alignments would reduce flood risk in a greater area but would also likely be longer, more expensive, and have greater environmental consequences. The inner alignments would offer flood risk reduction for smaller areas but may also have fewer implementation challenges (see "Boston Harbor and Harbor-Wide Flood Protection," p.115).

adaptation, and considerations of how flood protection would impact or be impacted by neighborhood character and growth.

The *location and design options* of flood protection systems determine their positive and negative impacts and implementation feasibility. In connecting areas of high ground to one another, many flood protection systems must span more than one type of location or design. Location and design options for district-scale flood protection include the following:

- **In-water.** Within a water body, a flood protection project would likely be an operable gate. In-water defenses can restrict navigable channels. In addition, they are likely to require higher elevations to protect against flooding due to wave heights, which can block visual and physical access to water.
- **Water's edge.** At the water's edge, there are many types of potential flood protection designs. As with in-water barriers, defenses at the water's edge are likely to require higher elevations to protect against flooding due to wave heights.
- **Upland.** There are many types of flood protection designs upland from the water as well. Compared to in-water or water's edge defenses, upland flood protection systems provide a comparatively smaller area of risk reduction. However, they are not likely to be as tall as defenses in the water or at the water's edge, since the ground elevation is higher, and wave energies dissipate over land. Still, upland flood protection can interfere with visual and physical connections within a neighborhood. In addition, they may cross roads, requiring deployable gates, or cross privately owned land.

See "Example Flood Protection Designs" (p.102) for a sample of various design options.

INITIATIVE 5-4. LAUNCH A HARBOR-WIDE FLOOD PROTECTION SYSTEM FEASIBILITY STUDY.

The City, in collaboration with regional partners, should study the feasibility and desirability of a harbor-wide flood protection system and compare it to the alternative of multiple district-scale defenses, using a consistent evaluation framework (see Initiative 5-2, p. 106). Partners may include the Metropolitan Area Planning Council (MAPC) and its Metro Boston Climate Preparedness Task Force. In addition, early and frequent engagement with the Massachusetts Office of Coastal Zone Management and U.S. Army Corps of Engineers would be critical, as well as ongoing engagement with the Boston Harbor Islands National and State Park. Studying such a significant intervention in detail is a major undertaking in its own right, and such studies elsewhere have been multiyear efforts requiring significant public resources and structured coordination.

As part of comparing the feasibility and desirability of multiple harbor-wide and district-scale alternatives using a consistent evaluation framework (see Initiative 5-2, p.106), a study would need to consider a number of location and design options for a harbor-wide intervention, including the following:

- **Alignment options.** A harbor-wide intervention could potentially occur along one of multiple different alignments. The outermost alignment would stretch from Deer Island and across the Harbor Islands (most likely Lovell's Island) to the Hull Peninsula. An alignment closer to the shore would stretch from Deer Island across Long Island to Moon Island in Quincy. Finally, an Inner Harbor alignment would stretch from Logan Airport to Castle Island. As a very basic comparison, the outer alignments would reduce flood risk in a greater area but would also likely be longer, more expensive, and have greater

environmental consequences. The inner alignments would offer flood risk reduction for smaller areas, but may also have fewer implementation challenges.

- **Sizes of gaps and gates.** For each approach to a harbor-wide intervention—only decreasing tidal range, and doing so with an operable surge barrier—there are questions related to the optimal size of harbor openings, with respect to both reducing flood risk and minimizing negative impacts. A feasibility study would need to explore how narrow the harbor mouth would need to be in order to sufficiently reduce the tidal range to reduce flood risk. For the surge barrier option, there would be some narrowing of the harbor mouth by virtue of the in-water infrastructure necessary to support the barrier. A feasibility study would need to explore the size, number, and locations of gates necessary to provide flood risk reduction while minimizing the impacts on the environment and navigation. For both options, attention must be paid to how the tide levels and salinity of the harbor would change, along with the consequences for local and regional ecosystems.

- **Project phasing.** Based on best practices from other locations, it is critical that resilience solutions be adaptable and flexible. Any harbor-wide intervention would be a very large investment, built to reduce flood risk for generations to come. However, as discussed in the Climate Projection Consensus (see p.01) there is uncertainty regarding future sea levels after about 2050, both because of the complex nature of climatic systems and because they are heavily dependent on the success of global efforts to reduce emissions. To address this uncertainty, the City should explore how to minimize the probability of designing to too high or too low a standard. For example, it may be worthwhile to narrow the tidal range in a way that would accommodate the addition of a surge barrier at a later point in time.

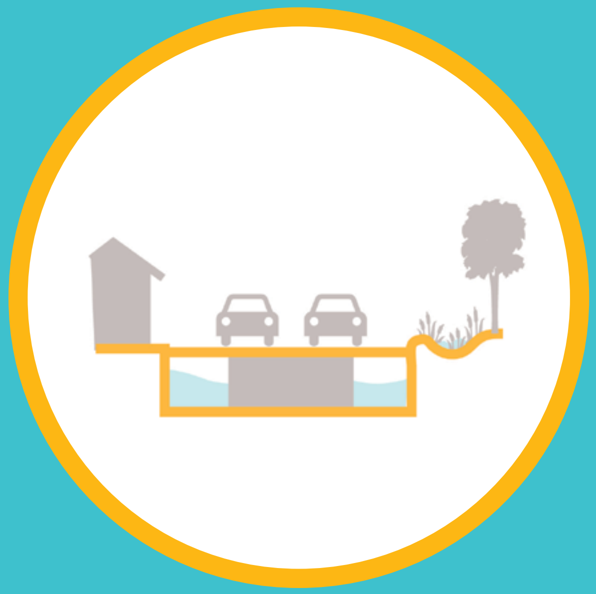
BOSTON HARBOR AND HARBOR-WIDE FLOOD PROTECTION

The challenges of implementing a harbor-wide flood protection system, as well as the potential environmental impacts, are significant. However, Boston Harbor also has distinctive characteristics that may make it more amenable to a harbor-wide flood protection system than are other cities' harbors:

- **Harbor depth.** The harbor is relatively shallow. Aside from the major shipping channels, which have been dredged to accommodate large vessels and are currently being deepened, much of the harbor is about 20 feet deep. The $310 million Boston Harbor Dredging Project will deepen the Outer Harbor 40-foot channel to 51 feet, the Inner Harbor 40-foot channel to 47 feet, and the Reserved Channel to 47 feet. Feasibility studies of channel narrowing or barrier construction should consider the impact of channel deepening.
- **Public land.** Almost all of the land that would need to be incorporated into a harbor intervention—from Deer Island through the Harbor Islands—is publicly owned and therefore can more readily accommodate a public flood protection project.

There are also a number of factors that would make construction of a harbor-wide flood barrier challenging, including impacts on ecological communities resulting from changing tidal conditions and salinity levels; the impacts on water quality because of decreased exchange of water between the harbor and the ocean; the potential for conflicts with commercial shipping, recreational boating, and water transportation; and the risk of inducing flooding in areas on the Atlantic Ocean side of a harbor-wide flood defense.

Source: "Boston to Begin Dredging in 2017." The Journal of Commerce, November 2015.



Layer 4

RESILIENT INFRASTRUCTURE

Strategy 6: Coordinate investments to adapt infrastructure to future climate conditions

INITIATIVE 6-1. ESTABLISH AN INFRASTRUCTURE COORDINATION COMMITTEE

RESILIENCE RATE CASE

The utilities that serve the Boston metro region may seek funds for resilience capital projects as part of their rate cases to the Massachusetts Department of Public Utilities (DPU) so that they can cover the costs of required resilience investments. For example, Con Edison included a $1 billion request for funds to support resilience capital upgrades from 2013 to 2016 as part of its electric, gas, and steam rate cases filed in January 2013. Should the utilities pursue this approach in Boston, the City may want to consider whether to support such a request. The Greater Boston Panel on Climate Change could be available to provide expert testimony about future climate conditions and the need for resilience investments to address utility system vulnerabilities.

STANDARDS DEVELOPMENT WORK TO DATE

In developing system standards, the ICC should leverage significant work done by its members to date. For example, the Boston Water and Sewer Commission has developed recommendations for the 10-year, 24-hour design storm, annual rainfall totals, and elevation at which outfalls are required to be tide-gated. In addition, the Massachusetts Port Authority has developed recommendations for design flood elevations as part of a new flood-proofing design guide. For existing facilities, the design flood elevation is the maximum water elevation with a 0.2 percent annual probability of exceedance in 2030 based on the Boston Harbor Flood Risk Model (BH-FRM), plus three feet of freeboard. For new facilities, the design flood elevation is defined by the maximum water elevation with a 0.2 percent annual probability of exceedance in 2070 based on the BH-FRM, plus three feet of freeboard. The Massachusetts Department of Transportation has put forward recommendations for elevations at which to deploy temporary and permanent protections for Central Artery and tunnel assets.

ICC Formation

The Mayor should work with the Governor of Massachusetts and other key stakeholders to establish a standing Infrastructure Coordination Committee (ICC), consisting of key private and public infrastructure owners and operators in the Boston metro area. The ICC should serve as the primary vehicle for coordination between the City and these entities on how to set design standards and track investments in climate resilient infrastructure. The committee also can be used as a framework to support coordination on other issues, as required.

The continued reliability of the infrastructure systems that meet Boston's transportation, water and sewer, energy, communication, and other needs is necessary for both Boston's continued prosperity and its residents' safety and health. The ICC is needed because Boston does not have direct control over all of the infrastructure that serves its population and economy, relying partially on regional systems. Climate Ready Boston's Vulnerability Assessment revealed that Boston's infrastructure systems are vulnerable to near-term and long-term climate impacts. Discussions conducted through Climate Ready Boston's Infrastructure Advisory Group indicated that infrastructure owners and operators do not have full information on their systems' vulnerability to changing climate conditions, especially in regard to upstream and downstream impacts. Both the City and infrastructure operators have a vested interest in understanding and addressing vulnerabilities to create resilient infrastructure systems. The ICC should provide a forum to bring together the key actors who regulate, operate, and own infrastructure so they can align their efforts, in terms of both setting and implementing standards to meet future climate conditions.

The key members of the ICC should include representatives from all of the major infrastructure systems, including transportation, water and sewer, energy, telecommunications, and environmental

BOSTON-AREA ICC PRECEDENTS

The ICC should build on four important efforts that have been undertaken in Boston and the metro region to date to convene key public and private infrastructure operators about issues directly or indirectly related to resilience. For Climate Ready Boston, in 2015, the City convened the Infrastructure Advisory Group to collect data about vulnerable assets and infrastructure system interdependencies and discuss possible resilience initiatives. In 2016, the Boston Planning and Development Agency convened the Smart Utilities Planning Committee to do coordinated, proactive utility planning for the Dorchester Avenue corridor. In 2014, the Office of Emergency Management convened the Natural Hazards Mitigation Plan Steering Committee, comprised of representatives of key City departments and commissions with responsibility for hazard mitigation, to guide the Boston Natural Hazards Mitigation Plan Update. In 2011, as part of the process for preparing Massachusetts's first Climate Change Adaptation Report, a mandate of the 2008 Global Warming Solutions Act, the Massachusetts Executive Office of Energy and Environmental Affairs convened both the Climate Change Adaptation Advisory Committee and the State Agencies Steering Committee. Through these groups, Boston and the Commonwealth have started the process of building institutional knowledge and overcoming barriers to data sharing.

NON-BOSTON ICC PRECEDENTS

To date, there have been efforts to establish entities similar to the ICC in other cities, most notably in New York City. In 2008, Mayor Michael Bloomberg convened the New York City Climate Change Adaptation Task Force (CCATF), a group of public and private infrastructure operators, to assess climate risks to their assets and identify strategies to protect them. Mayor Bloomberg charged the CCATF with developing an inventory of at-risk infrastructure assets, supporting coordinated adaptation planning, and creating design guidelines for new infrastructure. The New York City Panel on Climate Change (NYCPCC), an independent body of climate scientists, advised the CCATF. In 2013, following Hurricane Sandy, Mayor Bloomberg convened the Special Initiative for Rebuilding and Resiliency (SIRR) to develop a comprehensive roadmap for resilience building in NYC, leveraging the work of the CCATF.

In addition, as part of Con Edison's electric, gas, and steam rate cases filed in January 2013, the New York State Public Service Commission convened the Storm Hardening and Resiliency Collaborative to provide guidance on how the funds should be spent. The collaborative brought together academic experts to support Con Edison in adaptation planning.

Sources: "A Stronger More Resilient New York." Special Initiative for Rebuilding and Resiliency, City of New York, June 11, 2013.
"Storm Hardening and Resiliency Collaborative Report." Consolidated Edison Company of New York Inc. December 4, 2013.

DEVELOPMENT OF STANDARDS BY ICC WORKING GROUPS

WORKING GROUP	KEY MEMBERS	STANDARDS TO BE DEVELOPED
WATER AND SEWER	Boston Water and Sewer Commission, Massachusetts Water Resource Authority, Department of Conservation and Recreation, Public Improvement Commission	• 10-year, 24-hour design storm • Annual rainfall totals • Elevation at which public and private outfalls are required to be tide-gated • Elevation and level of protection requirements for assets critical to maintaining service • Performance design standards
TRANSPORTATION	Massachusetts Bay Transit Authority, Massachusetts Department of Transportation, Massachusetts Department of Conservation and Recreation, Boston Transportation Department, Boston Public Works Department	• Elevation and level of protection requirements for assets critical to maintaining service (roads, bridges, tunnels, rail, subways, buses, water transit, and transportation support facilities) • Performance design standards
ENERGY	Eversource, National Grid, Veolia, Boston Environment Department, Massachusetts Department of Public Utilities	• Elevations and level of protection requirements for critical assets and facilities • Performance design standards
TELECOMMUNICATIONS	Verizon, Comcast, Department of Innovation and Technology	• Elevations and level of protection requirements for assets critical to maintaining service • Level of access and continuity of service for broadband and Wi-Fi access • Performance design standards • Redundancy

assets, that are critical to the City of Boston's operations. These individuals should include participants from City departments, state agencies, private utilities, and adjacent municipalities that interact with or affect Boston's infrastructure systems. The ICC will be coordinated closely with the Metro Boston Climate Preparedness Task Force, which has been convened by the Metro Mayors Coalition.

ICC Duties

To strengthen Boston's resilience, the ICC should be charged with four duties:

First, the ICC should use the updated climate projections to develop planning and design standards across member agencies for retrofitting or constructing all major infrastructure systems to a standard set of future climate conditions. The ICC should work with the City to define levels of acceptable risk. Members should be organized into working groups by major infrastructure system, with the groups to include transportation, water and sewer, energy, telecommunications, and environmental assets, in order to develop specific planning and design standards by system.

Second, ICC members should collaborate to identify cascading vulnerabilities and opportunities for joint adaptation projects that could improve effectiveness or cost efficiencies by addressing multiple systems' vulnerabilities at once. The ICC should provide a framework for members to detect and reduce vulnerabilities that fall within larger systems that affect their assets but are out of their direct control. In addition, the ICC should provide a forum for members to share information, consult with each other about adaptation projects they plan to individually undertake, and work together to identify efficiencies and important community co-benefits, including advancing equity.

Third, ICC members should develop adaptation plans, tied to capital improvement plans, in order to upgrade their vulnerable assets over time to meet the agreed-upon planning and design standards. ICC members can use the Climate Ready Boston Vulnerability Assessment data as the basis for their adaptation planning. However, they may need to conduct asset-specific vulnerability assessments. Members should be asked to develop adaptation plans within five years of the initial planning and design standards being released. These plans should consider adaptation both across their systems as well as within specific focus areas prioritized by the City for coordinated adaptation planning. Capital projects should be prioritized based on the following:

- Timing and level of assets' exposure to climate change risks
- Consequences of assets' full or partial failure, including frequency and severity of service disruption
- Cost and feasibility
- Opportunity to advance equity and protect socially vulnerable populations. The City should charge ICC members with paying particular attention to vulnerable populations who may be disproportionately impacted by full or partial infrastructure failure.

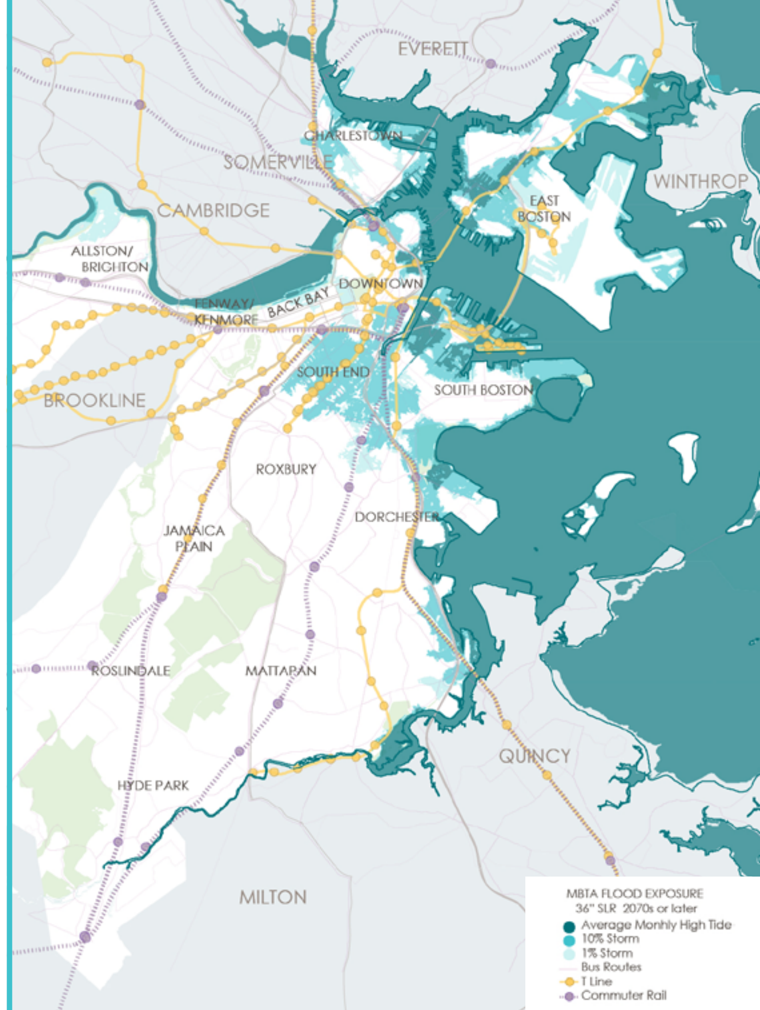
Finally, members should provide the City with regular reports on their progress in developing adaptation plans and bringing their assets up to planning and design standards. The Environment Department should annually summarize those reports to inform joint adaptation planning and identify gaps in adaptation across systems.

INITIATIVE 6-2. CONTINUE TO COLLECT IMPORTANT ASSET AND HAZARD DATA FOR PLANNING PURPOSES

To maximize the benefit of the data collected and produced as part of Climate Ready Boston, Climate Ready Boston should transfer non-confidential data on public and private infrastructure assets to the Department of Information Technology (DoIT). The objective of this initiative is to establish a central place for the storage of key data about infrastructure systems to create an integrated dataset and allow for the identification of upstream and downstream vulnerabilities. For the Vulnerability Assessment, Climate Ready Boston requested information on public and private infrastructure assets from a broad range of city and state agencies and private infrastructure operators, and reconciled and verified the submitted data. DoIT should coordinate with the Boston Regional Intelligence Center (BRIC) database to explore holding and storing data that is sensitive or proprietary.

INITIATIVE 6-3. PROVIDE GUIDANCE ON PRIORITY EVACUATION AND SERVICE ROAD INFRASTRUCTURE TO THE ICC

To guide adaptation planning by ICC members, the Office of Emergency Management (OEM), Boston Transportation Department (BTD), and Department of Public Works (PWD) should work with the utilities to identify roads to prioritize for adaptation planning. These roads should include first those that are part of Boston's evacuation network and second those that are required to restore or maintain essential services, for example, by delivering personnel or backup power (mobile generators or fuel) to critical facilities. OEM should share the list with the Massachusetts Department of Transportation (Mass DOT) and Department of Conservation and Recreation (DCR). The City should support Mass DOT in continuing its efforts to develop an emergency response plan for tunnel protection or closure in the event of a major storm, in line with the recommendations from the 2015 FHWA/Mass DOT Central Artery and tunnels vulnerability assessment.



MBTA VULNERABILITY ASSESSMENT

To support the ICC, the City should request that the Massachusetts Bay Transportation Authority (MBTA) expand its asset-level vulnerability assessment from the Blue Line, currently in progress, to its entire public transit system. Prior to the current Blue Line study, vulnerability assessment of the MBTA's assets and services has been limited to assets within the Central Artery corridor (e.g., South Station, Silver Line, Aquarium Station, and North Station) included in MassDOT's Federal Highway Administration-funded study. The MBTA's system-wide vulnerability assessment should include detailed analyses of physical infrastructure assets and supporting systems, and consider not only the relative importance of specific assets, but also their upstream and downstream interdependencies, with particular attention to the energy supplies on which MBTA's systems rely and potential impacts on vulnerable populations. The MBTA should consider the vulnerabilities of both the regional energy infrastructure on which it depends for maintaining service and its internal backup power supply, which ensures continued operation even when the power grid is unavailable.

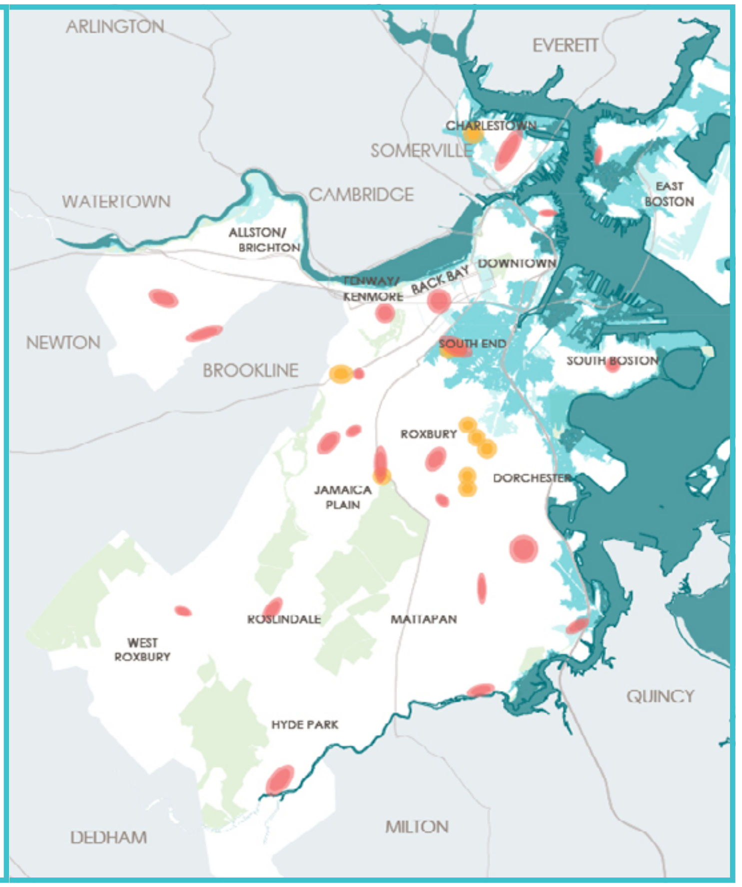
Strategy 7: Develop district-scale energy solutions to increase decentralization and redundancy

INITIATIVE 7-1. CONDUCT FEASIBILITY STUDIES FOR COMMUNITY ENERGY SOLUTIONS

The Boston Planning and Development Agency and Environment Department should work with the relevant members of the ICC and other stakeholders to use the findings from the BPDA's Boston Community Energy Study (2016) to develop action plans to pursue community energy solutions in areas with significant concentrations of critical facilities and socially vulnerable populations. Community energy solutions are local energy generation, energy storage technologies, district energy, and microgrids. The Community Energy Study identified 42 locations across Boston with high potential for community-based energy solutions, based on preliminary engineering and cost-benefit analyses. However, there is a need for further feasibility studies that evaluate other important factors, such as the state and capacity of existing infrastructure at potential sites, building retrofit costs, and street excavation costs. For example, parts of the Downtown, Charles River, and South Boston focus areas are served by an electrical grid that is not designed to export locally generated energy.

The BPDA and the Environment Department should prioritize further feasibility studies for potential energy justice and emergency microgrid sites, as identified by the Community Energy Study. Energy justice microgrid sites have the potential to serve clusters of affordable housing and critical facilities. Emergency microgrid sites have the potential to serve clusters of critical facilities.

PROPOSED COMMUNITY ENERGY SOLUTIONS



RAYMOND L. FLYNN MARINE PARK MICROGRID

The BPDA is working with Eversource to pursue a feasibility study for a pilot microgrid project at the Raymond L. Flynn Marine Park in South Boston.

Strategy 8: Expand the use of green infrastructure and other natural systems to manage stormwater, mitigate heat, and provide additional benefits.

With climate change, Boston faces more intense precipitation that will increase total stormwater volume and decrease water quality, rising sea levels that will inhibit stormwater outfalls from draining, and increasing temperatures. Under these conditions, large-scale expansion of green infrastructure in Boston has the potential to both increase the city's resilience and provide many co-benefits. Green infrastructure helps slow the pace of stormwater runoff, support on-site infiltration, and reduce pollutants entering waterways. It offers a decentralized approach to stormwater management that supports redundancy and adaptability because it can be expanded over time. It also may be less costly than gray infrastructure. Furthermore, green infrastructure can help mitigate the urban heat island effect by creating shade, reducing heat-absorbing materials, and emitting water vapor that cools the air. It also can help create an attractive environment, clean the air by filtering airborne pollutants, and reduce building energy costs through shading and recyclable water.[4]

[4] Source: "A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds." Stratus Consulting. August 24, 2009.

BOSTON'S USE OF GREEN INFRASTRUCTURE

In recent years, Boston has started to expand its use of green infrastructure, which encompasses a range of interventions, including porous pavement; bioswales; rain gardens; tree planters; green streets, alleys, and parking lots; green roofs; and constructed wetlands. Relative to gray infrastructure traditionally used to manage stormwater, green infrastructure has the potential to provide numerous environmental, economic, and social co-benefits.

In 2012, BWSC reached an agreement (consent decree) with U.S. Environmental Protection Agency and the Conservation Law Foundation to address pollution caused by stormwater runoff as required by the Clean Water Act, after these organizations asserted that BWSC was not moving quickly enough to do so. Under the agreement, BWSC committed to a seven-year plan to find and remove illegal sewage connections and expand its use of stormwater management best practices, including green infrastructure. BWSC also agreed to prepare a report identifying the stormwater best management practices most suitable for use in Boston, and to construct three demonstration green infrastructure projects at Central Square in East Boston, Audubon Circle, and City Hall Plaza. BWSC has provided the capital funding for these projects but partnered with BTD and PWD, which control the sites and are doing transportation upgrades, to construct the green infrastructure. BWSC also has agreed to fund and perform three years of required maintenance for these projects but does not have an ongoing maintenance plan beyond that.

In addition to BWSC, local nonprofits, including the Charles River Watershed Association (CRWA), have supported green infrastructure in Boston. CRWA led the development of two green infrastructure demonstration projects at Everett Street in Allston and Peabody Square in Dorchester, and also created a set of Green Street Guidelines for Allston-Brighton that identify potential green infrastructure interventions on three pilot streets.

Finally, the City has been actively supporting green infrastructure. The Boston Transportation Department incorporated green street strategies into Boston's Complete Streets Design Guidelines. In addition, the Boston Parks and Recreation Department has installed rain gardens in multiple city parks, and is evaluating opportunities for additional locations with current design projects.

Source: Marks, Alex. "Stormwater Management in Boston: To What Extent Are Demonstration Projects Likely to Enable Citywide Use of Green Infrastructure" MIT Thesis. 2014.

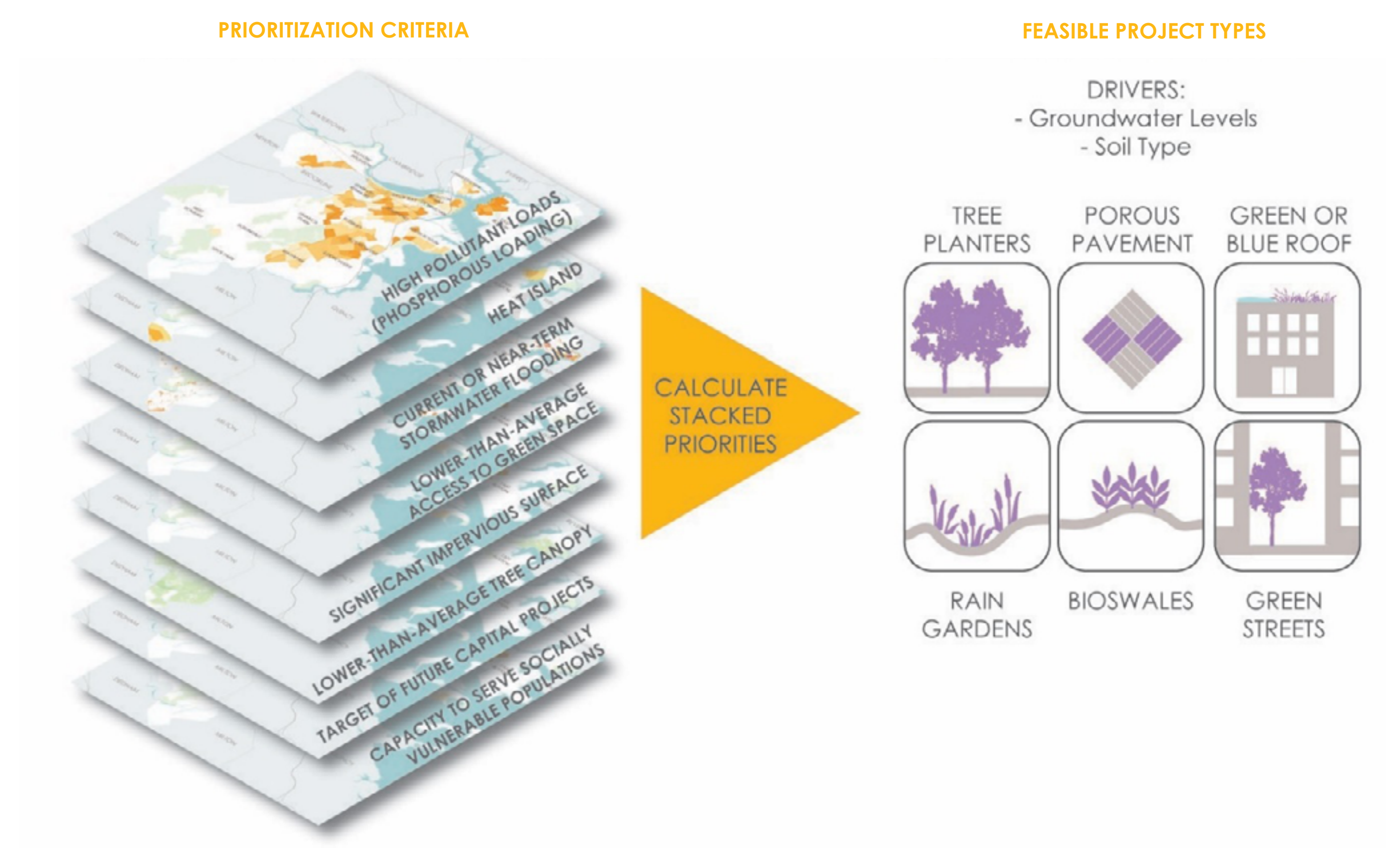
INITIATIVE 8-1. DEVELOP A GREEN INFRASTRUCTURE LOCATION PLAN FOR PUBLIC LAND AND RIGHTS-OF-WAY

The City should work with the Boston Water and Sewer Commission to develop a green infrastructure location plan for public land and rights-of-way in Boston. The green infrastructure location plan should identify high-priority sites for green infrastructure development, focusing on existing public land but also considering potential future public land that could be acquired to support multifunctional green space. This green space would provide stormwater management and other benefits. The purpose of the green infrastructure location plan is to increase the volume of water managed on-site on public land, as well as to identify potential opportunities to manage off-site stormwater.

The Energy, Environment, and Open Space Cabinet, which includes the Environment Department and Parks Department, should lead this effort, with the participation of other relevant City agencies, such as the Transportation Department, Public Works Department, and Boston Public Schools. The Boston Water and Sewer Commission is currently conducting a comprehensive analysis of its drainage system to identify high-priority locations for green infrastructure in Boston based on this type of infrastructure's capacity to reduce total pollutant loads. The Energy, Environment, and Open Space Cabinet should supplement this analysis by developing a set of other green infrastructure location prioritization criteria that serve other goals. Potential criteria are shown on the opposite page.

GOAL	PRIORITY LOCATIONS FOR GREEN INFRASTRUCTURE
IMPROVE WATER QUALITY TO MEET FEDERAL STANDARDS	Areas with high pollutant loads
MITIGATE CURRENT AND FUTURE CLIMATE CHANGE HAZARDS (EXTREME HEAT)	Areas that are daytime or nighttime land surface temperature hot spots (heat islands)
MITIGATE CURRENT AND FUTURE CLIMATE CHANGE HAZARDS (STORMWATER FLOODING)	• Areas that are subject to current or near-term stormwater flooding (lie at low elevations and have limited hydraulic capacity) • Upstream areas where green infrastructure construction could help reduce downstream stormwater flooding • Areas with large amounts of impervious surface
PROVIDE EQUITABLE ACCESS TO GREEN SPACE THROUGHOUT BOSTON	Neighborhoods with lower-than-average access to green space, especially those with high concentrations of socially vulnerable populations
IMPROVE NEIGHBORHOOD LIVABILITY AND HEALTH AND SERVE SOCIALLY VULNERABLE POPULATIONS	• Areas with higher-than-average air pollution levels • Areas with lower-than-average tree canopy
LEVERAGE PLANNED CAPITAL UPGRADES SO THAT GREEN INFRASTRUCTURE CAN BE INCORPORATED INTO THESE PROJECTS	Areas targeted for future capital projects, such as parks or roads upgrades

SITING GREEN INFRASTRUCTURE



To refine this list of criteria, the Energy, Environment, and Open Space Cabinet should draw on four sources:

- The findings from Climate Ready Boston;
- The green infrastructure location analysis currently being done by the Parks and Recreation Department for the assets that it owns;
- The Trust for Public Land's work on green infrastructure prioritization throughout Boston developed as part of its Climate Smart Cities initiative; and
- The Boston Water and Sewer studies to identify high-potential locations for green infrastructure based on pollutant loading and to define the most feasible types of green infrastructure for these locations.

The City and BWSC then should collaborate to create a green infrastructure location plan that shows sites that meet multiple criteria so that they can be prioritized for green infrastructure construction.

INITIATIVE 8-2. DEVELOP A SUSTAINABLE OPERATING MODEL FOR GREEN INFRASTRUCTURE ON PUBLIC LAND AND RIGHTS-OF-WAY

The City should work with the Boston Water and Sewer Commission to develop a sustainable operating model for green infrastructure on public land, including trees. Currently, the lack of a sustainable funding and operating model for green infrastructure on public land is a major barrier that has limited its large-scale deployment. Green infrastructure assets require different maintenance procedures than gray infrastructure assets and must be properly maintained to preserve their functionality. Green infrastructure maintenance should be tied to efforts to support workforce development and inclusive hiring (see Strategy 3, p.95).

The Energy, Environment, and Open Space Cabinet should lead this effort, with the participation of other relevant City agencies, such as the Budget Department. The Energy, Environment, and Open Space Cabinet should be charged with four tasks. First, it should establish a clear division of responsibilities that defines which entities are responsible for constructing, maintaining, and evaluating the performance of different types of green infrastructure. Second, it should evaluate the total capital and operating and maintenance costs associated with large-scale deployment of green infrastructure in Boston and recommend a "triple bottom line" approach to evaluating costs and benefits. An excellent model is the framework developed by Philadelphia that considers long-term financial, social, and environmental benefits against costs.[5] Third, the Energy, Environment, and Open Space Cabinet should recommend a toolkit of green infrastructure financing strategies to support both capital and operating and maintenance costs, recognizing that Boston may require new sources of funds to expand green infrastructure use. Fourth, it should identify opportunities to create streamlined, standardized green infrastructure maintenance processes that create cost efficiencies. The Energy, Environment, and Open Space Cabinet should review best practices from other cities that are national leaders in the large-scale deployment of green infrastructure, such as New York City, Philadelphia, Washington, DC, Seattle, and Portland.[6]

PHILADELPHIA'S "GREEN CITY, CLEAN WATERS" GREEN INFRASTRUCTURE PROGRAM

In its 2009 Combined Sewer Overflow Long-Term Control Plan, "Green City, Clean Waters," Philadelphia committed to invest $1.6 billion over 20 years to create a citywide network of green stormwater infrastructure, as opposed to a single, multi-billion dollar, 35-foot-diameter tunnel under the Delaware River. Philadelphia's green infrastructure best practices include the following:

- Establishing a large-scale program, focused on converting one-third of Philadelphia's existing impervious surface (about 4,000 acres) to green infrastructure
- Using a "triple bottom line" approach to evaluate the benefits of green infrastructure compared to gray infrastructure
- Setting up both regulatory requirements and financial incentives (stormwater credits for constructing and maintaining green infrastructure) to promote private provision of green infrastructure
- Developing a green infrastructure audit program to help customers with high stormwater fees to reduce their fees through green infrastructure implementation

Source: "Green City, Clean Waters: The City of Philadelphia's Program for Combined Sewer Overflow Control."

Amended by the Philadelphia Water Department, June 1, 2011.

[5] Source: "A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds." Stratus Consulting, August 24, 2009.

[6] Source: "Green City Clean Waters: The City of Philadelphia's Program for Combined Sewer Overflow Control." Amended by the Philadelphia Water Department, June 1, 2011.

INITIATIVE 8-3. EVALUATE INCENTIVES AND OTHER TOOLS TO SUPPORT GREEN INFRASTRUCTURE

The City and Boston Water and Sewer Commission should evaluate a set of incentives and other tools to reduce impervious surfaces, increase on-site stormwater retention and management, and create green infrastructure on public and private property. For example, the City can explore the creation of a green infrastructure revolving fund and a system that provides owners with savings on their water bills in exchange for green infrastructure creation and maintenance. To fund incentives and other tools, the City and the Boston Water and Sewer Commission should consider a stormwater fee, which has been implemented effectively in other municipalities. The Boston Water and Sewer Commission is currently evaluating the feasibility of such a program. If implemented, the stormwater fee would charge property owners based on the amount of impervious surface on their property. BWSC's feasibility study should include an evaluation of the fee's economic impact on different types of property owners, particularly low-income owner-occupants and affordable housing providers.

STORMWATER REGULATION IN BOSTON

BWSC issues stormwater permits for new private development in Boston, and has the authority to require on-site stormwater retention and "other stormwater management measures" (Source: Section 14, Article IV, "Regulations Governing the Use of Sanitary and Combined Sewers and Storm Drains of the Boston Water and Sewer Commission"). In general, BWSC requires property owners to infiltrate a volume of rainfall on-site equal to no less than one inch across the surface. The Groundwater Conservation Trust oversees stormwater management in the designated Groundwater Conservation Overlay District (GCOD) under Article 32 of the Boston Zoning Code. The GCOD requires projects to infiltrate a volume of rainfall on-site such that the project results in no negative impact on groundwater levels. The Boston Planning and Development Agency also is able to institute site plan requirements as part of the Article 80 process.

INITIATIVE 8-4. DEVELOP DESIGN GUIDELINES FOR GREEN INFRASTRUCTURE ON PRIVATE PROPERTY TO SUPPORT CO-BENEFITS

The City should request that the Boston Sewer and Water Commission develop design guidelines and set maintenance protocols for green infrastructure on private property to encourage installations that deliver significant co-benefits, such as increased access to green space. In addition to their efforts to support green infrastructure on public property through the green infrastructure location plan (see Initiative 8-1, p.124), the City and BWSC also should prioritize the development of green infrastructure on private property in order to introduce it into neighborhoods where there may be limited public sites. Stormwater flooding in Boston tends to primarily impact residential buildings, making on-site solutions attractive.

BWSC is well positioned to develop design these guidelines following the completion of its studies to identify feasible locations and types of green infrastructure. The current trend in Boston has been for property owners to install dry wells, which are expensive but need to be properly maintained to function effectively. BWSC does not have retrofitting requirements for sites that were built prior to its requirements.

The BPDA should evaluate the opportunity to reinforce these design guidelines through changes to the Boston Zoning Ordinance. This approach has been used successfully by the City of Portland. In Portland, the Stormwater Management Manual outlines design guidelines, which are authorized by Portland City Code Chapter 17.38, passed in 2008 and therefore enforceable.[7] In conjunction with development of the design guidelines, the BRA and BWSC should assess the need to provide incentives to achieve specific types of green infrastructure on private property.

[7] Source: Chai, Shutsu K. "Managing Stormwater in Watertown: Overcoming Obstacles to Change." MIT Thesis. 2009.

INITIATIVE 8-5. DEVELOP AN ACTION PLAN TO EXPAND BOSTON'S URBAN TREE CANOPY

Currently, the Parks and Recreation Department is planning to conduct an inventory of Boston's existing tree canopy to evaluate the current state of Boston's urban forest. Using the findings from this inventory, the Parks and Recreation Department should set criteria to prioritize where the City plants street trees. Expansion of Boston's tree canopy should support the City's green infrastructure efforts. Trees can help manage stormwater, mitigate heat in multiple ways, and reduce air pollution.

The City should explore strategies to overcome physical barriers to the establishment of large trees in Boston. Large trees contribute significantly to Boston's canopy and are less likely to die than smaller trees, but they require space and a sufficient volume of soil for roots to thrive. The City must balance many priorities when planning its sidewalks, such as safely accommodating pedestrians and providing space for needed furniture, but street trees should be an important part of this equation. In its new Complete Streets Guidelines, the City has set standards for sidewalk construction that establish preferred and minimum widths for the greenscape and furnishing zone, ranging from 6 to 1.5 feet. The City should collaborate with private partners to implement the preferred standards in the development of new sidewalks or retrofitting of existing sidewalks, while still meeting American with Disability Act requirements for a minimum pedestrian zone of 4 feet, to support the establishment of large trees.

In addition, as part of its climate readiness education campaign, the City should conduct outreach to private property owners about the importance of designing and constructing around existing trees, avoiding tree removals, and protecting large trees on private property.

The City should establish a Heat Overlay District in neighborhoods with the highest need for trees to help coordinate the actions of public and private actors. The District could perform the following functions:

- Set larger tree pit-size minimum requirements and increase the use of structural soil and permeable pavements where pit size is constrained. The City's Complete Streets Guidelines have set the minimum width of the greenscape and furnishing zone necessary to support street tree installation as 2.6 to 6 feet.
- Require utilities and PWD to set protection of existing trees as a primary goal in projects, so that existing trees do not always lose out to space for bike lanes, parking, or utilities.
- Establish a review process for removal of trees over a certain size on private properties.
- Establish minimum lot shade coverage requirements for private properties.

INITIATIVE 8-6. PREPARE OUTDOOR FACILITIES FOR CLIMATE CHANGE

As an ICC member, the Parks and Recreation Department should develop an adaptation plan, tied to a capital investment plan, to prepare its outdoor facilities for climate change. The Parks and Recreation Department will identify facilities where resilience improvements are needed to address near-term flooding impacts, and evaluate whether the improvements are feasible to incorporate into existing planned capital upgrades or will require a new work stream. To address extreme heat, the Parks and Recreation Department will evaluate opportunities to increase shade trees and structures, reduce heat-absorbing surfaces, and add "spray" water features and water fountains as part of all capital upgrades.

INITIATIVE 8-7. CONDUCT A COMPREHENSIVE WETLANDS INVENTORY AND DEVELOP A WETLANDS PROTECTION ACTION PLAN

The Conservation Commission should conduct a comprehensive wetlands inventory to define priority sites for wetlands restoration and inland buffer areas that must be protected to enable habitats to migrate inland as sea levels rise. The wetlands inventory should consist of mapping all existing wetlands, analyzing the functions (ecosystem services) performed by them, and identifying sites that are of high resource value and are at high risk due to development or climate impacts.

Following the completion of this inventory, the Conservation Commission should develop an action plan for protecting wetlands to preserve environmental quality and help in protecting against climate impacts. The action plan should define the pathways that the City can use to protect wetlands, including regulation (e.g., a Local Wetlands Ordinance) and acquisition of key sites. This could include a Local Wetlands Ordinance (LWO) that enables the Conservation Commission to protect additional wetlands types, protect already-covered types to a greater degree, and take future climate impacts into account during project review. The LWO could give the Conservation Commission jurisdiction over a buffer area adjacent to lands subject to current coastal storm flowage, based on likely sea level rise, and establish performance standards for all protected areas.

WETLANDS REGULATION IN MASSACHUSETTS

Depending on their location and attributes, wetlands have the opportunity to mitigate all three types of climate risks that Boston is facing: extreme heat, stormwater flooding, and coastal and riverine flooding. Coastal wetlands can help reduce the speed and force of waves coming onshore during storm surge events and can prevent water from coming inland if the wetlands have elevated edges. Inland wetlands can help convey and filter stormwater runoff and reduce flow into stormwater treatment systems. Due to their vegetation, wetlands can mitigate urban heat. Wetlands also absorb large quantities of carbon dioxide from the atmosphere, accumulated over hundreds and thousands of years, and store it as carbon sinks, thereby helping to mitigate global warming. Tidal wetlands are at risk from sea level rise and need to have the ability to migrate inland, or they may be lost, even with restoration efforts. Wetlands loss not only prevents future carbon capture but also releases stored carbon, increasing greenhouse gas levels in the atmosphere.

Currently, the Boston Conservation Commission regulates activities in coastal and inland wetland resource areas through the Commonwealth's 1972 Wetlands Protection Act (WPA) and accompanying regulations. The WPA recognizes eight important public values or functions provided by wetlands and protects them in 12 types of Coastal Resource Areas and 5 types of Inland Resource Areas. Coastal Resource Areas include Lands Subject to Coastal Storm Flowage (LSCSF), which perform important functions related to protecting from storm damage and assisting with flood control. Individuals performing any work that removes, fills, dredges, or alters any resource area must obtain a permit, or Order of Conditions, from the Conservation Commission that defines requirements to be met before, during, and after the work.

While the state WPA provides protection to many types of wetlands, it has some limitations. First, the state WPA does not protect all types of wetlands. Second, while it defines specific performance standards for Inland Resource Areas, it does not establish specific performance standards for Coastal Resource Areas or buffer areas. Coastal Resource Areas have general standards or none at all. Work done within buffer zones can have significant impacts on Coastal Resource Areas. Third, it does not allow the Conservation Commission to take into account projected future or cumulative effects of climate change, including sea level rise, when reviewing project impacts. However, the Commonwealth allows municipalities to enact local wetlands ordinances that enable them to protect more wetlands types; protect existing types to a greater extent, including by establishing performance standards; and take into consideration future conditions. The City should support state efforts to develop performance standards for Coastal Resource Areas and evaluate the role of a local wetlands ordinance.

Layer 5

ADAPTED BUILDINGS

Strategy 9. Update zoning and building regulations to support climate readiness

These initiatives build on the Boston Planning and Development Agency's Resiliency Policy, which has required all large project proposals to analyze and describe their climate preparedness through a Climate Preparedness Checklist since 2013. Boston should now take the next step of incorporating climate readiness across its building regulations.

Current zoning and building codes do not yet institutionalize climate readiness:

- **Current regulations do not consider future climate conditions.** Building standards for flooding refer to FEMA's Flood Insurance Rate Maps (FIRMs), which are based on historical information. While a building constructed to these standards may be climate ready today, as sea levels rise, it will face continuously increasing risk.
- **Current regulations discourage adaptation.** In order to become more climate ready, many buildings would need to elevate their first floors and mechanical systems. However, regulatory limits on height and bulk often discourage such elevations.
- **Current regulations foster a site-scale approach to climate readiness.** While individual new and renovated buildings have some requirements to build to certain climate-ready standards, there are no regulatory mechanisms to build in a way that would provide broader district-scale flood risk reduction and address the impact of individual retrofits and adaptation projects on overall flood risk and urban design. Regulations also do not protect the beneficial functions of storm damage prevention and flood control provided by the coastal floodplain.

The initiatives under this strategy follow three basic principles:

- **The City should prioritize areas in which it has independent authority.** While the City controls its own zoning code and can directly amend it, it does not control the building code and will therefore need to work with the Commonwealth (see Background: Regulatory Context for Buildings, p.133).
- **The City is the ultimate long-term investor in all local properties.** While individual and institutional property owners have a limited time horizon for owning certain properties and therefore may not want to invest in long-term solutions or interventions where benefits accrue to future owners, the City has a moral and financial interest in making sure that buildings remain safe and maintain their value for generations. This is especially true in Boston, where approximately two-thirds of City revenues come from the property tax.[8] To continue to offer quality services, the City must protect its tax base in both the short and the long term.
- **Flexibility and adaptability are essential; there is more than one way to prepare for climate change.** Many buildings built today will still be standing at the end of the century. At that time, as described in the Climate Projection Consensus (see p.01), sea levels are likely to be three to seven feet higher. Given this range, it is possible to build in ways that will allow adaptation over time. For example, one approach for new buildings would be to have high ground-floor ceilings so that the ground floor can be raised as sea levels rise over time, without creating undesirably low floor-to-ceiling heights.

[8] Source: "Revenue Estimates and Analysis for Fiscal Year 2017." Boston Office of Budget Management. 2016.

BACKGROUND: REGULATORY CONTEXT FOR BUILDINGS[9]

BUILDING CODE

In Massachusetts, the building code is established at the state level by the Board of Building Regulations and Standards (BBRS) and administered at the local level by the City of Boston's Inspectional Services Department (ISD). The City does not have authority to establish building code requirements that are stricter than the state building code without approval from the Commonwealth (see Initiative 9-5, p.138).

In the Massachusetts Building Code, flood-resistant construction standards apply to all new or substantially renovated structures within the Special Flood Hazard Area (SFHA), as defined by the currently effective FEMA Flood Insurance Rate Maps (FIRMs). The SFHA is the area exposed to a 1 percent annual chance flood, and most areas within the SFHA are assigned a base flood elevation (BFE), the elevation to which floodwater is expected to rise during a 1 percent annual chance flood. FIRMs outline three subareas within the SFHA:

- Zone V, subject to wave action with wave heights of 3 feet or more;
- Coastal Zone A, subject to wave action with wave heights of 1.5 to 3 feet; and
- Non-Coastal Zone A, subject to waves less than 1.5 feet in height.

The 8th Edition of the Building Code, which is currently in effect, requires the following for new or substantially renovated structures:

- In Zone V, the lowest horizontal structural member is required to be elevated at least two feet above the BFE
- In Coastal and Non-Coastal Zone A, lowest floors are required to be elevated at least to the BFE.

In early 2016, the BBRS approved a draft of the 9th Edition of the Building Code, which requires public review and final approval before it takes effect. The draft update includes the following new requirements for new or substantially renovated structures:

- In Coastal Zone A, the requirements for Zone V apply; and
- In Non-Coastal Zone A, the lower floor is required to be elevated, and the building equipment is required to be elevated or flood-proofed to at least one foot above the BFE. Facilities essential for emergency response and recovery, or that contain hazardous materials, require elevation to two feet above the BFE or the 500-year flood elevation, whichever is higher.

ZONING CODE

The Boston Zoning Code is shaped by the Boston Planning and Development Agency (BPDA), adopted by the Boston Zoning Commission (BZC), and enforced by the Inspectional Services Department (ISD). The following articles of the Zoning Code are most relevant for climate readiness:

Article 25 is Boston's flood-resistant construction zoning requirement. The City adopted Article 25 in order to comply with the National Flood Insurance Program, which requires municipalities to adopt flood-resistant construction standards before any property owners in the municipality can buy federally backed flood insurance. Article 25 does not contain any additional requirements beyond those included in the Massachusetts Building Code.

Article 80 sets forth guidelines for four types of BPDA development review: small projects (adding more than 20,000 square feet), large projects (adding more than 50,000 square feet), planned development areas (new overlay zoning districts for project areas larger than 1 acre), and institutional master plans (projects relating to academic and medical campuses). The review process can include an assessment of a project's impacts on transportation, the public realm, the environment, and historic resources.

Article 37 is Boston's green building zoning requirement, administered by the Interagency Green Building Committee (IGBC). It requires all projects 50,000 square feet or larger to be certifiable under the U.S. Green Building Council's LEED process. Since 2013, the BPDA has also required all large projects to complete a Climate Preparedness and Resiliency Checklist, which is also reviewed by the IGBC. In the checklist, applicants document the climate-preparedness measures incorporated into the project's design.

Article 32 created Boston's Groundwater Conservation Overlay District. It is monitored by the Boston Groundwater Trust. The purpose of the article is to ensure projects do not reduce groundwater levels in specific areas to prevent wooden pilings under buildings from rotting. Developers are required to conduct a study of their project's effect on groundwater and install recharge systems for excavation, construction, and rehabilitation of any area greater than 50 square feet.

WETLANDS PROTECTION ACT

The Massachusetts Wetlands Protection Act (M.G.L. Ch. 131, § 40) and Regulations (310 CMR 10.00) are designed to ensure that the public's interests in wetland resource areas are preserved. In Boston, the regulations are administered by the Conservation Commission. The jurisdiction of these regulations includes coastal beaches and dunes, intertidal flats, salt marshes, eelgrass, ponds, lakes, rivers, streams, and flood zones (defined as Special Flood Hazard Areas on the currently effective FEMA Flood Insurance Rate Maps) as well as 100-foot buffer zones around wetlands.

[9] Source: "Incorporating Improved Coastal Flood Resiliency Measures into Boston's Waterfront Regulations." Boston Harbor Now Climate Resilience Committee. 2016.

SUMMARY OF INITIATIVES TO UPDATE ZONING AND BUILDING REGULATIONS

#	INITIATIVE	RELEVANT REGULATION OR PROCESS	RECOMMENDED CHANGES
9-1	**Establish a planning flood elevation to support zoning regulations in the future floodplain**	Boston Zoning Code	Establish a **Planning Flood Elevation** for all buildings within the future 1 percent annual chance flood zone.
9-2	**Revise the zoning code to support climate-ready mechanical systems**	Boston Zoning Code	Using the **Planning Flood Elevation** (Initiative 9-1), amend provisions of the Zoning Code (allowable height, bulk, and use) to ensure they promote and do not discourage **climate-ready new construction and retrofits.**
9-3	**Promote climate readiness for projects in the development pipeline**	Development Approval Process	Offer developers with already-approved project an opportunity to adopt **climate ready new construction standards** (Initiative 9-2) based on the **Planning Flood Elevation** (Initiative 9-1) without needing to undergo a completely new City review process.
5-1	**Establish Flood Protection Overlay Districts and require potential integration with flood protection systems (see Protected Shores layer, p.98)**	Boston Zoning Code	Establish a **new overlay district in potential flood protection locations** and require that development proposals do not prevent the **future creation of flood protection infrastructure.**
9-4	**Pursue state building code amendments to promote climate readiness**	Massachusetts Building Code	Advocate to the state to adopt a new **minimum elevation for building mechanical systems** based on the **future 1 percent flood elevation** at the end of a system's design life.
9-5	**Incorporate future climate conditions into area plans**	Strategic Planning Areas, Planned Development Areas, Municipal Harbor Plans, and Institutional Master Plans	**Incorporate future climate considerations** into major neighborhood planning efforts.

INITIATIVE 9-1. ESTABLISH A PLANNING FLOOD ELEVATION FOR ZONING REGULATIONS IN THE FUTURE FLOODPLAIN

The Boston Planning and Development Agency (BPDA) should petition the Boston Zoning Commission to revise the zoning code to incorporate the extents and depths of future flooding, as documented in appropriate future flood maps (see Initiative 1-2, p.84). This would be a first step toward correcting a flaw in Boston's current floodplain regulations, which is that they rely on FEMA Flood Insurance Rate Maps that are based primarily on historical flood data and therefore do not include risk due to a changing climate.

In order to incorporate the extents and depths of future flooding, the BPDA should establish a planning flood elevation (PFE) for each project through the following steps:

- Institute standard planning time periods for new buildings, which may vary based on construction type. In the existing Climate Change Preparedness and Resiliency Checklist, the BPDA generally requires that large buildings in Boston consider climate change for at least the next 60 years.
- Use future flood projections (see Initiative 1-2, p.84) to determine whether each project is expected to be within the future 1 percent annual chance floodplain during the applicable planning time period.
- For each project within this future floodplain, determine the 1 percent annual chance flood elevation at the end of the planning time period. This is the planning flood elevation (PFE).

As noted under Background: Regulatory Context for Buildings (see p.133), Boston does not have the authority to mandate minimum elevations for buildings. However, Boston can incorporate the PFE into zoning regulations to both remove obstacles for existing buildings that want to voluntarily adapt, and require new buildings to be built to standards that would encourage future adaptation (*see Initiative 9-2*).

INITIATIVE 9-2. REVISE THE ZONING CODE TO SUPPORT CLIMATE-READY BUILDINGS

The Boston Planning & Development Agency (BPDA) should petition the Boston Zoning Commission to revise the zoning code to ensure regulations on the use, height, and bulk of buildings promote and do not discourage climate-ready new construction and retrofits. Under current regulations, property owners may avoid elevating their properties or mechanical systems or taking other climate-readiness measures because they would be violating the zoning code or sacrificing buildable area.

The BPDA should also ensure that the zoning revisions encourage a quality streetscape and pedestrian activity even as buildings are elevated and flood-proofed. The elevation or flood-proofing of a building's first floor could create a blank wall, leading to an uninviting streetscape, but this effect can be counteracted through design solutions such as planters, raised yards, front steps, or latticed walls.

The following are potential revisions to the Boston Zoning Code that could support climate-ready buildings and desirable urban design. Each requires further analysis to evaluate financial and design implications.

POTENTIAL ZONING REVISIONS	APPLICABLE FOR EXISTING BUILDINGS?	APPLICABLE FOR NEW BUILDINGS?
Measuring the maximum height of a building within a future floodplain from the building's PFE, rather than from grade. This would allow owners to build or retrofit to climate-ready standards without sacrificing buildable area.	●	●
Allowing first floors that are below the PFE to be converted to a use other than for human occupancy, wet flood-proofed, and removed from the total floor area calculation. This could not only reduce the occupants' flood risk and owners' insurance costs, but it could also allow the addition of new stories to buildings with the necessary structural capacity. The revenues from the addition of new stories could help finance the building retrofits.	●	
Allowing subgrade basements in the future flood zone to be filled in and removed from the total floor area calculation.	●	
Allowing mechanical systems, cables, and other wiring equipment to be elevated above the PFE and removed from total floor area calculation, or allowing mechanical systems to be moved outdoors, if such a move is required to achieve the elevation of systems without sacrificing buildable floor area. The movement of mechanical systems outdoors must not interfere with egress paths.	●	
Explicitly permitting temporary flood control devices in setbacks and public access areas in ways that reduce the potential for adverse impacts to adjacent properties.	●	●
Requiring that the minimum ceiling height for ground floors be measured from the PFE. This would result in additional ground-floor floor-to-ceiling height so that, as sea levels and flood elevations rise, buildings can adapt by raising the first floors while still maintaining desirable floor-to-ceiling heights.		●
Requiring that buildings raised significantly above grade feature ground-level design elements that activate the street. This would prevent the negative impact on pedestrian experience that can occur when buildings are elevated and feature only blank exterior walls below the first floor. Elevated commercial spaces can also retain their ground-floor storefront and provide access (stairs and ramps) to the raised first floor as part of an indoor vestibule.	●	●
Increasing the total roof area that solar panels can cover without counting as an additional floor.	●	●
Requiring or incentivizing design elements, such as planted green roofs or high-reflectance cool roofs, which limit stormwater runoff or mitigate the urban heat island effect.	●	●

INITIATIVE 9-3. PROMOTE CLIMATE READINESS FOR PROJECTS IN THE DEVELOPMENT PIPELINE

Upon amending the zoning code to support climate readiness (see Initiative 9-2, p.135), the BPDA should immediately notify all developers with projects in the development pipeline in the future floodplain that they may alter their plans in a manner consistent with the zoning amendments (e.g., raising their first-floor ceilings without violating building height limits) without needing to go through the entire BPDA permitting process again. The BPDA should notify the owner/developer, architect, engineer, and contractor of record for each project. The BPDA would assess the legal bounds of instituting this expedited review process. Other local, state, or federal approvals may still be necessary.

There are currently hundreds of projects in Boston that have been approved for construction but not yet built. Many of these projects are in areas that are either currently in the floodplain or will be during the life of the building, and the buildings have not been planned to incorporate future flood risk. Many developers are not aware of the future risk, and even if they are, they might not want to elevate their buildings and sacrifice buildable area. This proposed approach would encourage developers to make relatively small additional investments in climate readiness without sacrificing buildable area or delaying project timelines.

RELATED INITIATIVE:
INITIATIVE 5-1. ESTABLISH FLOOD PROTECTION OVERLAY DISTRICTS AND REQUIRE POTENTIAL INTEGRATION WITH FLOOD PROTECTION SYSTEMS

The City should establish a new overlay district in potential flood protection locations and require that development proposals do not prevent the future creation of flood protection infrastructure (see p.106 for more details).

INITIATIVE 9-4. PURSUE STATE BUILDING CODE AMENDMENTS TO PROMOTE CLIMATE READINESS

The City should ask the Massachusetts Board of Building Regulations and Standards to institute stricter requirements for new or substantially improved buildings in Boston. The key new requirement would be higher minimum elevation of mechanical systems. Similar to Initiative 9-2 (see p.135), this would correct the current approach by defining a building's mechanical system elevation requirement based on the local Boston flood map for the end of the equipment's design life.

There are three potential pathways toward incorporating future flood conditions into the state building code, and Boston should pursue the most expedient pathway:

- Under Massachusetts General Law Chapter 143 §98, the City may request that the BBRS allow higher standards to be applied specifically within Boston.
- The City can work with regional partners, such as the Metro Boston Climate Preparedness Task Force, to request that the BBRS adopt a Stretch Climate Readiness Code with increased construction requirements. All municipalities in the commonwealth would then have the option of adopting the Stretch Climate Readiness Code.
- The City can work with regional partners, such as the Metro Boston Climate Preparedness Task Force, to recommend that the BBRS incorporate higher standards into the building code throughout the commonwealth.

INITIATIVE 9-5. INCORPORATE FUTURE CLIMATE CONDITIONS INTO AREA PLANS

The Boston Planning and Development Agency (BPDA) should incorporate future climate considerations into major neighborhood planning efforts across the city, including Strategic Planning Areas, Planned Development Areas, Municipal Harbor Plans, and Institutional Master Plans, which are ultimately codified in zoning. Long-term projections for extreme heat, stormwater flooding, and coastal and riverine flooding must all be considered as key variables for planning the future of Boston's neighborhoods.

For Municipal Harbor Plans, which set requirements for building dimensions, public access, and public benefits for waterfront areas, the consideration of future coastal and riverine flooding is particularly important. Future plans should ensure that, as sea levels rise, public access areas are not reduced. Public access areas should be elevated above future high tide elevations and either raised above the PFE or constructed to withstand future inundation, including saltwater tolerant plantings, paving, and equipment. Municipal Harbor Plans should also investigate the possibility of requiring the elevation of entire waterfront sites, a strategy that can provide flood risk reduction for inland areas but must be evaluated for each site to avoid increasing flood risk for adjacent properties (see Initiatives 5-1 and 5-3, pp.106 and 110).

PRECEDENT: ALLOWING MUNICIPALITIES TO ADOPT HIGHER BUILDING CODE STANDARDS (MASSACHUSETTS STRETCH ENERGY CODE)

The Commonwealth adopted the Massachusetts Stretch Energy Code in 2009. It is an alternative stronger energy code that municipalities can choose to use instead of the base code. It increases efficiency requirements for all new residential and many new commercial buildings and for residential additions and renovations that trigger building code compliance. The code was adopted by the City of Boston in November 2010.

Strategy 10: Retrofit existing buildings

Context: The Challenge of Retrofitting Boston's Buildings

Boston's existing building stock is diverse. It includes a broad range of owner types that have different levels of both building management expertise and access to financing to undertake building- and site-scale resilience improvements. Many buildings are historic, and while still able to adapt, such buildings face unique challenges in doing so while maintaining their historic character and architectural significance. In the near term, over 2,000 buildings across Boston have at least a 1 percent annual chance of inundation by coastal and riverine flooding, and almost 9,000 are exposed to frequent stormwater flooding. Considering that Boston has many older buildings not adapted for flooding or extreme heat risks, the need for retrofits is great. The City should work with property owners to promote access to the information and financial resources that they need to prepare their buildings for climate change.

RELATED INITIATIVE: INITIATIVE 3-2. LAUNCH A CLIMATE READY BUILDINGS EDUCATION PROGRAM FOR PROPERTY OWNERS AND USERS

The City should develop and run an education program to inform property owners and other groups about current and future climate risks facing their buildings and actions they can undertake to increase their preparedness (see p.95 for more details).

INITIATIVE 10-1. ESTABLISH A RESILIENCE AUDIT PROGRAM FOR PRIVATE PROPERTY OWNERS

The City should establish a resilience audit program to help property owners identify potential building- and site-level resilience actions to address coastal and riverine flooding, stormwater flooding, and extreme heat. Through the Climate Ready Buildings Education Program, the City should encourage all at-risk property owners to evaluate their resilience.

To start, the City should prioritize the over 2,000 buildings that are exposed to coastal flooding at 9 inches of sea level rise under at least the 1 percent annual chance event. To further guide prioritization within this group, it should take into account exposure under more frequent events (monthly high tide and the 10 percent annual chance event), the criticality of functions housed within the building, exposure of socially vulnerable populations, and expected physical damages. A resilience audit should help property owners identify cost-effective, building-specific improvements to reduce flood risk, such as backflow preventers, elevation of critical equipment, and deployable flood barriers; promote interventions that address stormwater runoff or the urban heat island effect, such as green roofs or "cool roofs" that reflect heat; and encourage owners to develop operational preparedness plans and secure appropriate insurance coverage. The resilience audit program should include a combination of mandatory and voluntary, market-based and subsidized elements. This would be similar to the combination of energy audit requirements for large buildings in the City's Building Energy Reporting and Disclosure Ordinance (BERDO) and the subsidized, voluntary energy audits offered through the Renew Boston program.

Audits offered through a City program could include prequalified firms to conduct the resilience audits, reduced-cost audits for owners that demonstrate high levels of risk and financial need, and efforts to combine climate resilience audits with energy efficiency audits. Key internal partners for this effort include the Department of Neighborhood Development for at-risk affordable multifamily residential owners, the Boston

CURRENT AREA PLANNING INITIATIVES

The BPDA works with communities throughout the city to create area plans that guide long-term growth in Boston's neighborhoods. Three current planning initiatives are PLAN: Dudley Square; PLAN: South Boston Dorchester Avenue; and PLAN: Jamaica Plain / Roxbury. Among the many community priorities addressed in these and other plans, the BPDA should consider future climate conditions, including coastal flooding, stormwater flooding, and extreme heat, in order to help neighborhoods prepare.

A NOTE ON BUILDING REGULATIONS AND INCENTIVES

Many of the regulatory changes included here may increase the short-term costs of real estate development in Boston, even as they decrease risk and flood insurance costs. An alternative approach the City may pursue is to raise some required minimum standards, while offering incentives that motivate developers to exceed minimum standards. The City must think carefully about what resilience actions should be incentivized, as opposed to required. Developers may require incentives to take resilience actions if some of the benefits of such actions accrue to other property owners, or outside the developers' timeframe for evaluating investments.

RESILIENCY IMPROVEMENTS: COST AND FEASIBILITY FACTORS

FACTOR	CONSIDERATIONS
Flood Risk	
Annual chance flood depths	Higher flood depths present greater risk to buildings and reduce the range of potential feasible solutions.
Flooding frequency	Intermittent floods require different design solutions than regular flooding at high tide.
Wave action	Wave action increases flood depths, adds force against buildings, and potentially introduces debris. Wave action also impacts height and load requirements.
Moving water and channelization	Floodwaters can maintain significant momentum as they move landward, and can be channelized by solid foundations and other obstructions, resulting in increased velocity and volume of flow directed onto adjacent properties and infrastructure.
Structural	
Structure type	Structure type is an important factor in determining if dry flood-proofing, wet flood-proofing, or elevation is feasible.
Location of critical systems	The current location and required locations of critical systems are important in developing retrofit solutions.
Structural integrity	Structural reinforcement may be necessary but cost prohibitive or technically infeasible depending on the building.
Codes and standards	Substantially altering a building may trigger additional code and regulatory requirements that increase project costs.
Occupancy and operational requirements	The type of use may limit building layout options. For facilities that provide a public service, maintaining continuity of existing services is important and may lead to prioritization of mitigation actions that minimize impacts to current operations. ADA access and universal design considerations must be incorporated into resilient retrofits of public facilities.
Historic status	The historic status of the building may affect project design.

Home Center and Renew Boston for at-risk low- to moderate-income owner-occupants, and the Economic Development Department's Main Streets program for at-risk small businesses. Finally, the City should explore the creation of a system for disclosure of appropriate information from climate resilience audits, modeled after BERDO.

There are a number of factors that drive the cost and feasibility of resilience improvements. The table on page 68 summarizes factors related to coastal and riverine and riverine flooding, which generally presents a greater risk of structural damage to buildings than do the other hazards analyzed by Climate Ready Boston.

RESILIENCE AUDIT PROGRAMS

Existing Models in Boston

The City can leverage its existing energy efficiency audit programs as models for resilience audits. Renew Boston is a public-private partnership between the City, Eversource (formerly NStar), National Grid, Mass Save, community-based nonprofits, and Mass Save–certified contractors. The City launched the program in 2009, and it is funded by ratepayers through state requirements. Renew Boston offers free on-site energy efficiency audits (home energy assessments) to owners of single-family homes and small multifamily buildings with up to four units. Renters also are able to request audits. During the audit, the designated energy advisor may install energy-saving lightbulbs and power strips, low-flow shower and faucet heads, and programmable thermostats. The advisor then sends a follow-up report summarizing further recommended energy efficiency improvements and available funding sources. Through Mass Save, owners are eligible for a 75 percent discount (up to $2,000) for insulation and air-sealing services, with owners of two- or three-family buildings or condo owners complete recommended improvements building-wide able to receive a larger "whole building" discount. In the first half of 2016, Renew Boston completed more than 1,700 home energy assessments for owners and renters. Renew Boston also works with small businesses and large condominium associations and cooperatives. It offers a direct-install program that can pay for up to 70 percent of the total cost for retrofitting lighting and mechanical systems.

To guide the types of resilience improvements recommended under the audit program, the City can leverage existing responses to the Boston Planning and Development Agency's Climate Preparedness Checklist, plus two key reports by the Green Ribbon Commission and A Better City, "Building Resilience in Boston" (2013) and "Enhancing Resilience in Boston" (2015). The reports identified potential resilience actions that can be undertaken at the building and site level, their benefits, and their costs.

New York City Neighborhoods Multifamily-Specific Resiliency Technical Assistance Program

In partnership with the New York State Governor's Office of Storm Recovery, the Center for New York City Neighborhoods launched the Multifamily-Specific Technical Assistance Program (TAP) as a pilot program in 2016. The pilot program will provide 100 multifamily property owners serving low- to moderate-income residents in Sandy-impacted communities with on-site resilience audits by qualified engineering and building services firms, followed by one-on-one counseling to provide a set of recommendations for building resilience improvements based on the audit findings. Under a separate program, the Governor's Office of Storm Recovery also is working with community-based organizations to provide resiliency counseling to single-family building owners.

Source: "Request for Proposal for Resilience Counseling." Center for New York City Neighborhoods, Inc. June 15, 2016. http://www.renewboston.org/.

INITIATIVE 10-2. PREPARE MUNICIPAL FACILITIES FOR CLIMATE CHANGE

The Office of Budget Management (OBM), through its capital budget planning, will work with all City departments to prioritize adaptation projects to prepare at-risk municipal facilities for coastal and riverine flooding, stormwater flooding, and extreme heat risks. It is recommended that OBM use the findings from the Climate Ready Boston Vulnerability Assessment (see p.12) and the City's 2013 identification and prioritization of at-risk municipal facilities to identify at-risk facilities. OBM should prioritize facilities for retrofits based on three factors:

- Vulnerability, in terms of the timing and extent of exposure
- Consequences of partial or full failure, in terms of the number of users impacted, the likely duration of service interruption, and expected damage to the facility relative to market value or replacement value
- Criticality, with highest priority for impacts on life and safety

OBM may want to develop standardized risk scores to quantify, understand, and communicate relative risk among facilities. The OBM should partner with the Public Facilities Department to estimate the costs of adaptation projects. In addition, it should partner with Renew Boston Trust to evaluate the opportunity for resilience improvements to be combined with energy efficiency improvements.

To address coastal and riverine flooding risks, the City should prioritize adaptation at facilities exposed to flooding in the near term under 9 inches of sea level rise (1 percent or greater annual chance) that demonstrate high levels of criticality. In particular, the City should prioritize adaptation at police, fire, EMS, and Boston Housing Authority facilities that demonstrate both especially high levels of criticality and high frequency of exposure (e.g., exposed under the average monthly high tide or 10 percent annual chance flood event).

KEY MUNICIPAL FACILITIES EXPOSED TO NEAR TERM FLOODING

		EXPOSURE		
FOCUS AREA	FACILITY NAME	9 INCHES SLR AMHT	9 INCHES SLR 10% ANNUAL CHANCE STORM	9 INCHES SLR 1% ANNUAL CHANCE STORM
EAST BOSTON	Heritage Elderly Public Housing		●	●
	Engine 9, Ladder 2 (Fire)		●	●
	Police Department District A-7			●
DOWNTOWN	Ambulance 8			●
SOUTH BOSTON	EMS Harbor Patrol			●
	BPD Harbor Patrol			●
CHARLESTOWN	EMS Station 15			●

BOSTON HOUSING AUTHORITY FACILITIES AND FUTURE FLOOD EXPOSURE

Boston Housing Authority facilities are among the municipal properties that Boston should adapt to coastal and riverine flood risk. The City should prioritize adaptation at facilities exposed to flooding in the near term under 9 inches of SLR for high-probability events (10 percent annual chance event or monthly high tide). The map above shows Boston Housing Authority facilities and the extent of 1 percent annual chance flooding in the late century.

To address extreme heat risks, as well as other causes of power outages, the City should prioritize backup power installation at facilities that demonstrate high levels of criticality. The City should promote solar photovoltaic generation and storage because this method supports reduced greenhouse gas emissions. In particular, the City should prioritize backup power installation at emergency shelters, which include Boston Centers for Youth and Family and Boston Public School facilities that serve as such. The City should also evaluate the need for cooling capacity across its facilities. The City is currently installing solar photovoltaic battery storage to support critical loads for at least three days in the event of an extended power outage at four BCYF facilities that also serve as emergency shelters.

INITIATIVE 10-3. EXPAND BACKUP POWER AT PRIVATE BUILDINGS THAT SERVE VULNERABLE POPULATIONS

The City should support solar photovoltaic generation and storage in private buildings that serve vulnerable populations. These buildings would receive outreach under Initiative 2-3 (see p.92). Targeted facilities should include affordable housing complexes, substance abuse treatment centers, daycare facilities, food pantries, and small nonprofit offices, for example.

The Environment Department should leverage past analyses of high-potential locations for solar to identify sites for backup installations. For example, the Community Energy Study identified districts that are suitable for community solar projects based on a high density of rooftop solar potential (i.e., the capacity to support large-scale solar projects with a minimum 500 kW of solar production). The City also has partnered with Mapdwell to identify the rooftop solar potential of all residential and commercial buildings in Boston.

In addition, the Environment Department should partner with Renew Boston Trust to evaluate the opportunity for resilience improvements to be combined with energy efficiency improvements.

INITIATIVE 10-4. DEVELOP TOOLKIT OF BUILDING RETROFIT FINANCING STRATEGIES

Because expanded access to financing will facilitate resilient building retrofits, the City should identify a toolkit of financing strategies that could be used to fund retrofits for both municipal and non-municipal buildings. These financing strategies can tap public, private, and nonprofit capital to make retrofits accessible to Bostonians with a range of incomes.

The City should collaborate with firms conducting resilience audits to develop profiles of retrofit costs by different building types. The profiles should be used to size the resilience financing need and guide financing strategy development for different building types. The City should then work with key partners, including Boston's lending, asset management, and insurance communities, to evaluate ways to quantify and monetize the benefits of climate resilience improvements and create a market for resilience in Boston. These benefits can include direct economic gains (i.e., incremental property tax increases), avoided losses (i.e., avoided structural, contents, and inventory damage), and cost savings (i.e., savings from reduced energy and water usage).

Through Renew Boston Trust (see call-out box), the City should explore ways to subsidize resilience improvements with energy efficiency improvements. The City should also identify ways to incorporate resilience upgrades into planned capital improvements for both public and private buildings and realize cost efficiencies from doing so. For example, the City may be able to incorporate resilience upgrades into housing repair loan programs for low- to moderate-income owner-occupants supported by the Boston Home Center. The Boston Home Center offers permanently deferred interest loans for critical repairs, where the City recovers its costs when the home is sold.

For non-municipal buildings, the City should prioritize developing retrofit financing pathways for buildings that provide a public benefit, have high levels of exposure, and are likely to experience challenges accessing financing. These buildings include the following:

- Affordable housing projects
- Non-municipal community facilities, especially those that provide critical services to vulnerable populations (food pantries, daycare centers, substance abuse treatment facilities)
- Low- and moderate-income homeowners
- Small businesses, especially those serving low- to moderate-income communities
- Historic buildings, where preservation requirements, often important to neighborhood character, may increase retrofit challenges and costs

RENEW BOSTON TRUST

The City created Renew Boston Trust (RBT) in 2016 to expand financing for energy efficiency improvements in Boston by monetizing future savings. In theory, RBT offers a potential pathway to use the savings from energy efficiency improvements to cross-subsidize resilience improvements. Currently, the proposed RBT model is focused on energy efficiency improvements to two types of buildings:

- Municipal buildings: Under the proposed model, City departments with responsibility for buildings will submit energy efficiency capital projects to RBT. RBT will combine projects to create aggregations that meet strict underwriting criteria ensuring their future energy cost savings will cover repayment of their upfront capital costs. RBT then will establish a performance-based contract with an energy service contractor to design and install the aggregated project, with the contractor guaranteeing that the project will be done on time and deliver the promised savings. The City will advance the cost of the project, and be reimbursed over time using the savings or contractor guarantee payments.
- Nonprofit institutions that are able to use state and City finance authorities for tax-exempt borrowing: Under the proposed model, groups of smaller nonprofits will join together to submit an aggregated energy efficiency project to RBT, which will review the project structure and confirm that it meets strict underwriting criteria. The nonprofits will then request that a state or City finance authority pursue financing for the project on their behalf and hold title to it during the repayment period. The authority then will partner with a lender, who will advance the cost of the project, and establish a performance-based contract with an energy services contractor, who will do the project. The authority will provide the improvement to the nonprofits, and they will repay the lender through passed-through rent payments. At the end of the repayment period, the nonprofits will purchase the project from the authority.

Strategy 11. Insure buildings against flood damage

Affordable access to appropriate levels of flood insurance coverage is critical to protecting property owners' investments and neighborhoods' stability. Property owners with proper and affordable insurance can more easily recover from their losses after a flood event, while those without can face severe financial distress. Furthermore, properties without adequate insurance may remain in a state of disrepair, leading to negative economic and social impacts on their neighborhoods. The National Flood Insurance Program is the primary source of flood insurance for owner-occupants, smaller residential properties, and small businesses. Generally, large commercial businesses carry flood insurance purchased from private insurers.

INITIATIVE 11-1. EVALUATE THE CURRENT FLOOD INSURANCE LANDSCAPE

The City should conduct a study of the current flood insurance landscape in Boston for owner-occupant and multifamily residential buildings to identify affordability challenges created by recent legal changes to the National Flood Insurance Program (NFIP)[1] and the projected floodplain expansion. The City should evaluate the level of coverage in current and projected future high-risk floodplains (1 percent annual chance flood event) by number and type of buildings. It should use NFIP policyholder and claims data provided by FEMA to provide a baseline of existing coverage. It should also conduct outreach to property owners, managers, and industry practitioners to provide insight into current understanding of flood insurance laws, level of coverage, understanding of building-level risk, and willingness to undertake building- and site-level adaptations. The City should evaluate strategies to help property owners respond to major increases in insurance premiums.

INITIATIVE 11-2. JOIN THE NATIONAL FLOOD INSURANCE PROGRAM COMMUNITY RATING SYSTEM

The City should work with FEMA Region I staff and the Massachusetts Insurance Services Office to begin the process of participation in the National Flood Insurance Program's (NFIP) Community Rating System (CRS). The CRS is a voluntary incentive program that recognizes and encourages community floodplain management activities that exceed minimum NFIP requirements. Based on the extent of best practices used to reduce damage to insurable property, increase insurance coverage, and take a comprehensive approach to floodplain management, the CRS discounts citywide NFIP flood insurance premium rates. The discount applies to both public and private purchasers of insurance. In order to enter the CRS, Boston must enter a formal application with NFIP, conduct an inventory of at-risk assets and initiatives in place to address risks, conduct a site visit with FEMA, and engage in a 6- to 12-month evaluation process. Boston has a site visit scheduled with FEMA this year.

INITIATIVE 11-3. ADVOCATE FOR REFORM IN THE NATIONAL FLOOD INSURANCE PROGRAM

The City should collaborate with leaders in other major cities on the East Coast to support 2017 reforms to the National Flood Insurance Program (NFIP) that promote flood insurance affordability in Boston. Key items for advocacy include the following:

- Taking into account alternative or partial flood mitigation strategies—such as flood-proofing mechanical systems or moving some mechanical components above the base flood elevation—when determining flood insurance rates, instead of requiring buildings in the 100-year floodplain to comply with all NFIP guidelines in order to realize any rate reductions.
- Considering expanding the types of non-residential space that residential buildings are permitted to maintain below the base flood elevation beyond parking, lobbies, storage, and crawl space to potentially include uses that support residential dwelling units, such as laundry rooms, building management offices, or common spaces.[10]
- Establishing a district-scale NFIP Community Rating System so that Boston and other cities can receive credit for improving flood risk management neighborhood by neighborhood.

[10] Subsidies for certain NFIP policies are currently being phased out, resulting in premium increases of 18 to 25 percent per year. Certain policies are also facing increasing deductible limits and surcharges. The NFIP requires reauthorization by Congress in 2017 and may be substantially changed.

Image courtesy of Sasaki

Focus Areas

Eight Boston areas where the results of the Vulnerability Assessment and the climate resilience initiatives are applied in more detail to illustrate the risks Boston faces and how Boston can address them.

Image courtesy of Bud Ris

Charlestown

Charlestown, located on a peninsula just northwest of Downtown Boston, is surrounded by water on three sides. It is bounded to the south by the Charles River, to the north by the Mystic River, and to the east by Boston Harbor. It is connected to Downtown Boston by the Charlestown Bridge and the Leonard P. Zakim Bridge, to Chelsea by Maurice J. Tobin Bridge, and to Everett by the Malden Bridge.

Founded in 1629, Charlestown is the oldest neighborhood in Boston. It was originally a separate town before being annexed by Boston in 1874. Charlestown was originally surrounded almost completely by water, with an inlet of the Charles River (Miller's River) running along its southwest edge before intersecting with the Charlestown Neck, a thin strip of land connecting Charlestown Peninsula to East Somerville near Sullivan Square. This inlet has since been largely filled.

In 1800, the U.S. Navy established a shipyard along the eastern waterfront, promoting the growth of marine industrial uses in Charlestown, along with worker housing. The Charlestown Navy Yard was extensively used during World War II. The neighborhood then experienced some decline before becoming subject to urban renewal efforts in the 1960s and 1970s, which led to the Navy Yard's redevelopment for office, research, and residential uses and removal of the Charlestown Elevated rail line (running along Main Street from City Square to Sullivan Square).

Today, Charlestown is a thriving residential community, with a mixed housing stock consisting of brick and wood-framed row houses and waterfront condominiums and apartments. Charlestown also hosts the largest public housing development in Boston, the Bunker Hill Apartments, with 1,100 units for low- to moderate-income households. Due to its proximity to Downtown and historic housing stock, Charlestown has become attractive to young professionals.

Charlestown's main commercial corridors lie along Bunker Hill Street and Main Street. It also has major employment hubs at Bunker Hill Community College, the Navy Yard, Spaulding Rehabilitation Hospital, and the Boston Autoport. The Boston Autoport is located on an 80-acre site at the northeast corner of Charlestown, between the Mystic River and the Little Mystic Channel. To promote and protect water-dependent industrial uses along the Mystic River, the Commonwealth has established a Designated Port Area there. Charlestown also has industrial and commercial uses concentrated south of Rutherford Avenue. It also includes a number of historic landmarks, such as the Bunker Hill Monument/Monument Square National Register District and the *U.S.S. Constitution* and *U.S.S. Cassin Young* on the waterfront.

The City is currently planning roadway design improvements to Rutherford Avenue and Sullivan Square to create a more pedestrian-friendly environment and create opportunities for transit-oriented development adjacent to Sullivan Square.

Image courtesy of Sasaki

FLOOD PROGRESSION

DEFINITIONS

Near term: Beginning 2030s, assumes 9 inches of sea level rise

Midterm: Beginning 2050s, assumes 21 inches of sea level rise

Long term: Beginning 2070s or later, assumes 36 inches of sea level rise

Exposure: Can refer to people, buildings, infrastructure, and other resources within areas likely to experience hazard impacts. Does not consider conditions that may prevent or limit impacts.

Vulnerability: Refers to how and why people or assets can be affected by a hazard. Requires site-specific information.

Consequence: Illustrates to what extent people or assets can be expected to be affected by a hazard, as a result of vulnerability and exposure. Consequences can often be communicated in terms of economic losses.

Annualized losses: The sum of the probability-weighted losses for all four flood frequencies analyzed for each sea level rise scenario. Probability-weighted losses are the losses for a single event times the probability of that event occurring in a given year.

*For a full list of definitions, refer to the Glossary in the Appendix.

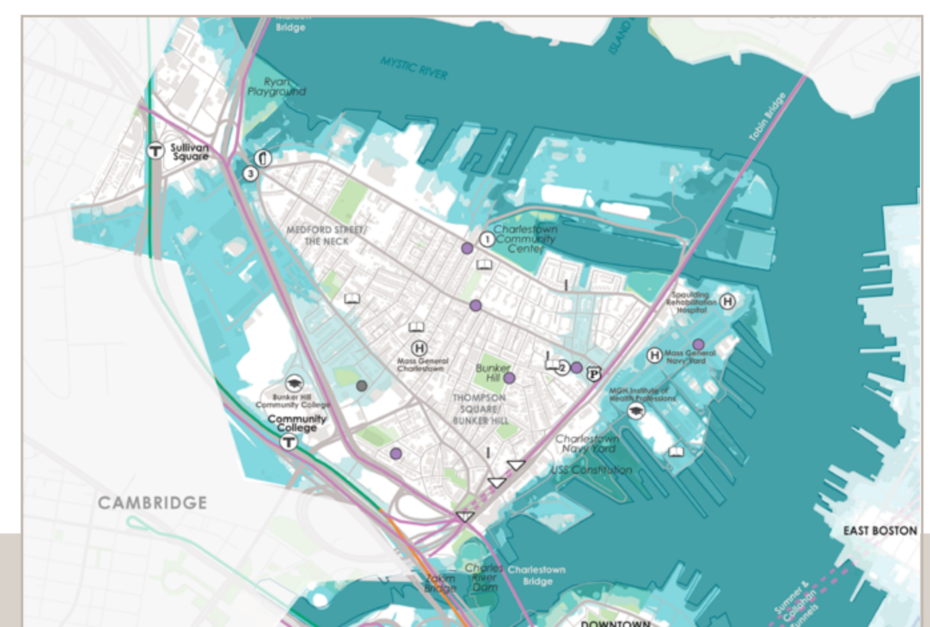
Charlestown is exposed to climate change impacts including heat, increased precipitation and stormwater flooding, and sea level rise and coastal and riverine flooding. Exposure to heat and stormwater flooding are addressed in the Citywide Vulnerability Assessment (see p.12), while exposure and consequences to coastal and riverine flood risk are further discussed in this section.

Charlestown's exposure to near-term impacts is limited to pockets of flooding near the Charlestown Navy Yard, the Boston Autoport near the Tobin Bridge, and low-lying land east of Sullivan Square.

Significant coastal flooding is likely by later in the century, with most of Charlestown's waterfront area extending from Cambridge to Somerville projected to be inundated during major coastal storms. Inland flooding would be greatest through low-lying land immediately east of Sullivan Square, and flooding would also extend through the Charles River Basin if the Charles River Dam were flanked.

9 INCHES SEA LEVEL RISE

21 INCHES SEA LEVEL RISE



36 INCHES SEA LEVEL RISE

LEGEND

- Average Monthly High Tide
- 10% Annual Chance Storm
- 1% Annual Chance Storm
- Parks
- Roads
- Major Roads
- Major Tunnels
- Evacuation Route
- Evacuation Route Tunnels
- MBTA Blue Line
- MBTA Station
- Tobin Bridge Tunnel Entrance
- College or University
- School
- Police Station
- Fire Station
- Hospital
- Health Care Facility
- MWRA DeLauri Pump Station
- Wind Turbine

Other Essential Facilities and Shelters

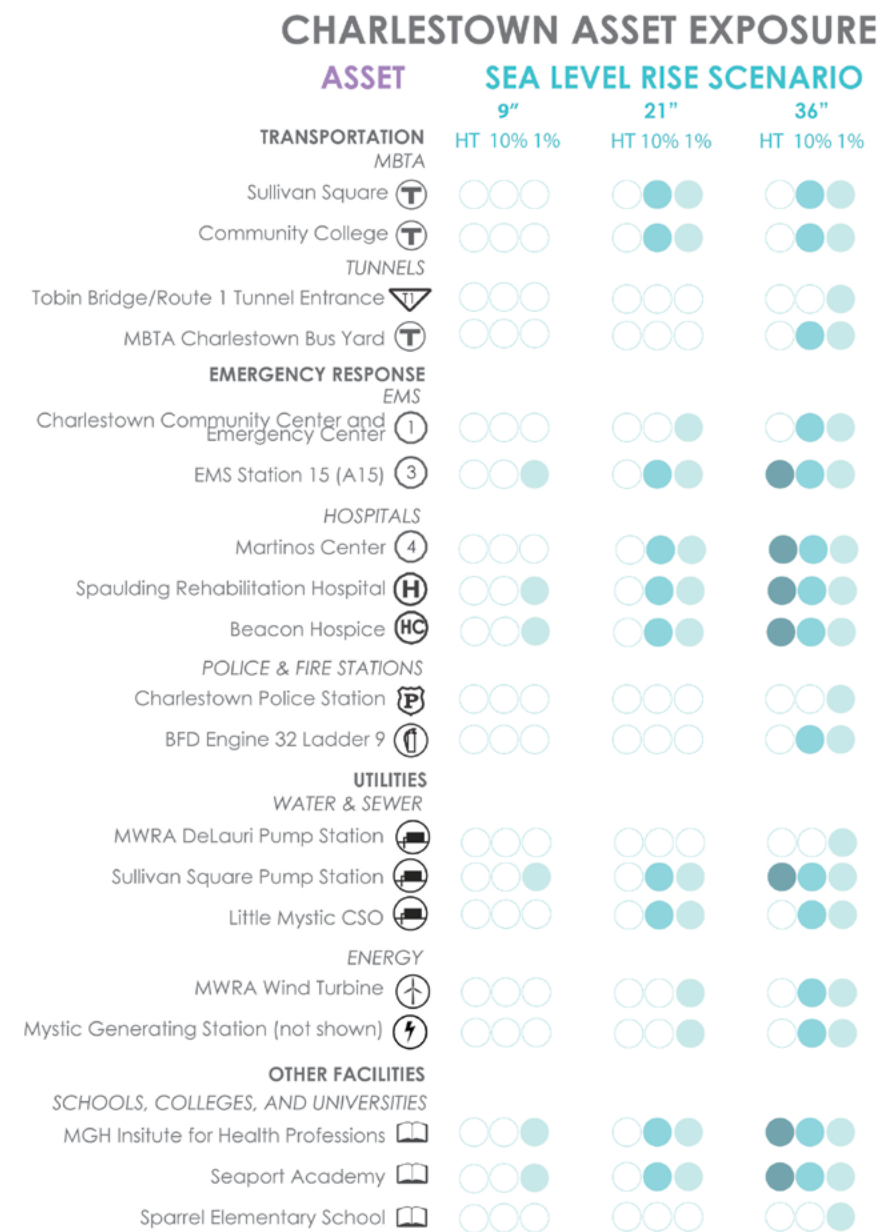
- 1 Charlestown Community Center
- 2 Kent Community Center
- 3 EMS Station 15 Ambulance 15
- BHA Public Housing
- Senior Housing
- Longterm Care Facility
- DCR Spray Deck or Pool

Land area in Charlestown exposed to flooding is in the top three for all coastal neighborhoods throughout the century. Over 50 percent of Charlestown will be exposed to coastal flooding during low-probability storms expected as soon as the 2070s (1 percent annual chance event).

Climate resilience planning must consider the broad flood extents near the waterfront that may affect the diverse mixture of buildings and industries, as well as the entry points for inland flooding near Sullivan Square and the Charles River Dam.

Prior to fill placement, Charlestown was a peninsula of relatively high ground, including the Bunker Hill neighborhood. In the late 1800s, Charlestown was built outward in all directions, including along the Mystic and Charles Rivers. **The majority of Charlestown's waterfront, composed largely of fill, will be exposed to coastal flooding, especially late in the century.**

In the near term, coastal flood extents remain largely along the waterfront edge, with the broadest flood extents near the Charlestown Navy Yard, the Boston Autoport near the Tobin Bridge, and low-lying land east of Sullivan Square. **As soon as the 2050s, the areas flooded in low-probability storms will increase by over 150 percent, mostly due to a large expansion of the floodplain inland via low-lying land near Sullivan Square.** Once coastal floods coming from the Mystic River cross Rutherford Avenue, a large expansion of the floodplain is expected to the south, along low-lying area that was filled. More frequent and expansive coastal flooding in inland areas of Charlestown is expected in the late century, with a higher probability of both flooding inland east of Sullivan Square and flooding associated with flanking or overtopping of the Charles River Dam. Areas exposed to low-probability events in the near term will be exposed to high tides later in the century, limiting access to or causing damage in areas like the Charlestown Navy Yard and Boston Harborwalk near Ryan Playground and the Malden Bridge.



EXPOSURE

POPULATION & INFRASTRUCTURE

POPULATION AND SOCIAL VULNERABILITY

Charlestown is currently home to more than 16,000 people. Charlestown has relatively lower concentrations of socially vulnerable populations than Boston at large. The exception is households with children, which make up 20 percent of households in the neighborhood compared to 17 percent citywide. The Seaport Academy and Sparrel Elementary School are exposed to low-probability events in the near term and low-probability late-century events, respectively. Impacts to schools may result in lost school days for children, and parents of small children may opt to miss work and stay home on these days. Charlestown has three senior housing developments, one long-term care facility, and six public housing developments where concentrations of elderly, medically ill, and low- to no-income residents live. Portions of two Boston Housing Authority developments, the Charlestown Apartments and Basilica Condos, are expected to be at risk for low-probability flood events later in the century.

In the near term, roughly 350 people currently live in areas expected to be flooded by monthly high tides, the second largest of all neighborhoods. In addition, over 420 people live in areas expected to be flooded by a high-probability flood event (10 percent annual chance), and 1,330 people live in areas expected to be flooded by a low-probability flood event (1 percent annual chance), making Charlestown the fourth most-exposed focus area, behind East Boston, Downtown, and South Boston.

In a significant expansion of risk, over 1,070 people currently live in areas expected to be flooded by monthly high tides as soon as the 2070s, an increase of roughly three times over the near term. Over 3,920 individuals live in areas expected to be flooded by high-probability events (10 percent annual chance), and 5,180 people live in areas expected to be flooded by low-probability events (1 percent annual chance). As soon as the 2070s, close to 500 people may require emergency shelter under low-probability events (1 percent annual chance), a number that outstrips Charlestown's current 300-person shelter capacity. Furthermore, Charlestown's existing shelter capacity will be exposed to lower probability events later in the century. The Charlestown Community Center and emergency shelter will be exposed to low-probability (1 percent chance) mid-century storms, potentially reducing the neighborhood's current shelter capacity by about 175 people. Available and accessible public shelters and effective communication regarding shelter alternatives will thus be critical to Charlestown residents.

CHARLESTOWN POPULATION EXPOSURE

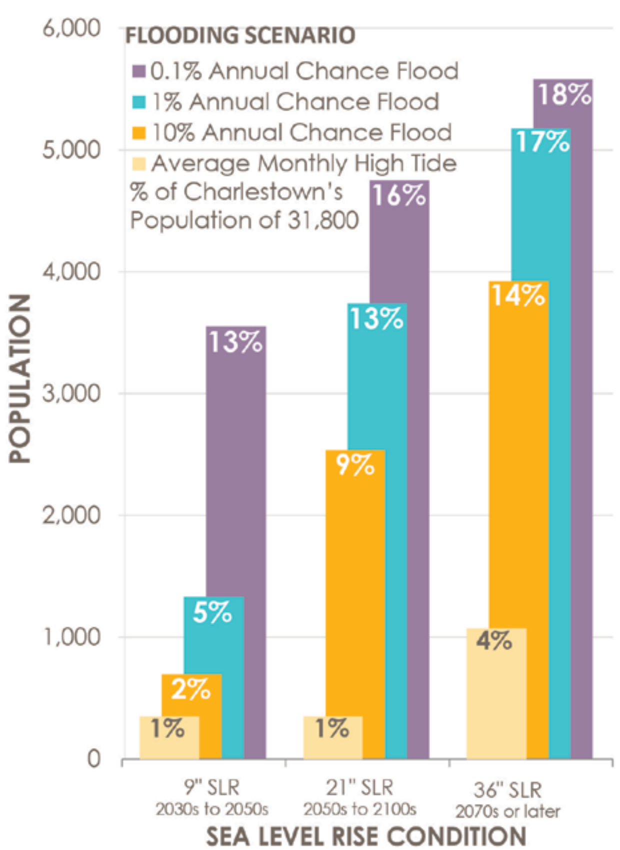


Image courtesy of Sasaki

INFRASTRUCTURE

Exposure of Orange Line MBTA stations and I-93 to low-probability mid- century storms and sea level rise may compromise connectivity between Charlestown and Downtown Boston.

Charlestown is separated from the rest of Boston by the Charles River and the Boston Harbor. The neighborhood is connected to Downtown Boston by the MBTA Orange Line, I-93, and Rutherford Avenue. Flooding at both Orange Line stations in Charlestown would not only restrict Downtown access but also access to Bunker Hill Community College, especially for students who rely on the light rail to attend class. If both the Community College and Sullivan Square Stations are rendered inoperable, over 15,000 individuals[1] that enter at those stations would be in need of alternative transportation options. This does not include potential impacts and service disruption if flooding penetrates into the transportation corridor.

I-93 and Rutherford Avenue are also two of Charlestown's three major evacuation routes. Flooding of these areas presents complications to safe evacuation, and avoidance of flooded areas can lead to overstressed and crowded side streets when drivers seek alternative routes. Rutherford Avenue near Sullivan Square, and the BWSC Sullivan Square stormwater pump station that protects it, are also expected to be exposed to floodwaters in the near future.

The Mystic Generating Station and Charlestown Wind Turbine, which contribute to Greater Boston's power supply and wastewater operations, will be exposed to low-probability storms in the second half of the century, and frequent storms in the late century.

The Mystic Generating Station is one of Massachusetts's major non-nuclear electricity generating plants. The facility is expected to be exposed to low-probability events by the second half of the century and more frequent (high-probability) storms later in the century. The station has a sophisticated emergency response plan in place to protect public health and safety in case of a disaster. Nevertheless, liquid natural gas currently from the Everett marine terminal, located across the Mystic River, is critical for operation.[2]

The Charlestown Wind Turbine generates three million kilowatt hours of electricity per year, and the power generated is net-metered to offset MWRA electricity costs, savings ratepayers approximately $350,000 a year. Though the turbine itself is not directly exposed to damage from coastal storms and sea level rise, it is expected to be surrounded by water during frequent storm events late century, potentially causing damage to underground infrastructure that transmits energy generated, as well as affecting safe access. Direct flood exposure is not expected at the DeLauri sewer pump station (where the wind turbine is located) during this century. The Little Mystic Combined Sewer Overflow facility may be exposed to frequent mid-century flooding but is expected to be able to continue operations throughout the century, based on MWRA's assessment.[3]

[1]Based on 2014 MBTA ridership and service statistics. Number only captures station entries and does not include all passengers traveling on the line as it passes through the station.

[2]Everett's exposure to coastal storms and sea level rise are not considered within the scope of this project.

Charlestown may experience reduced emergency response capacity as a result of sea level rise.

Charlestown's only EMS station, the Charlestown Police Station, and one of two fire stations are expected to be exposed to flood impacts at various points throughout the century. Maintaining operations at these essential facilities is critical in Charlestown to ensure that public health and safety needs are met during and after a flood event, especially considering that the neighborhood's physical connections to the Boston mainland may also be compromised.

All of Charlestown's hospital and medical research facilities will be exposed to high-probability flood impacts as soon as the 2050s, as well as late-century tides, impacting access to healthcare as well as some of the neighborhood's top economic drivers.

Four hospitals and medical research facilities are located on Charlestown's waterfront: Beacon Hospice, Spaulding Rehabilitation Hospital, MGH Institute of Health Professionals, and the Martinos Center for Biomedical Imaging. Spaulding Rehabilitation Hospital is a 132-bed rehabilitation teaching hospital owned by Partners HealthCare that opened in 2013. It was designed to be resilient and is expected to be protected in a low-probability event in the near future. Existing flood mitigation measures at the site are expected to cut late-century annualized storm impacts in half.[4]

[3]Inferred from critical flood elevation data provided by MWRA.

[4]Based on Climate Ready Boston analysis.

EXPOSURE AND CONSEQUENCES

BUILDINGS AND ECONOMY

RISK TO BUILDINGS

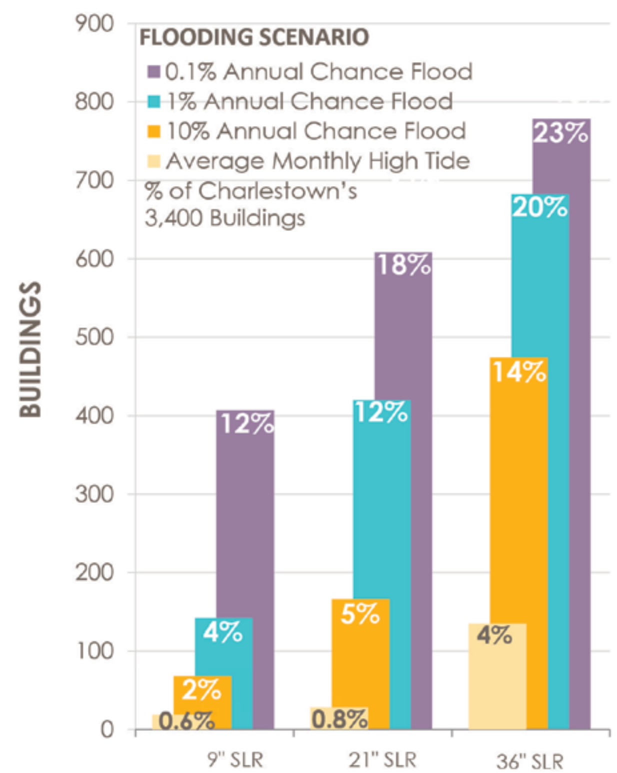
The majority of exposed buildings in Charlestown are residential and mixed-use structures.

Charlestown is mostly residential in character; residential-only properties make up nearly 60 percent of the neighborhood's total number of structures and 60 percent of the current real estate market value.[5] Charlestown's housing stock is made up of primarily low-rise row houses and wood-framed two- or three-family buildings. Though much of Charlestown's housing is elevated, structures typically have basements or below-grade finished space and are often vulnerable through windows at grade.

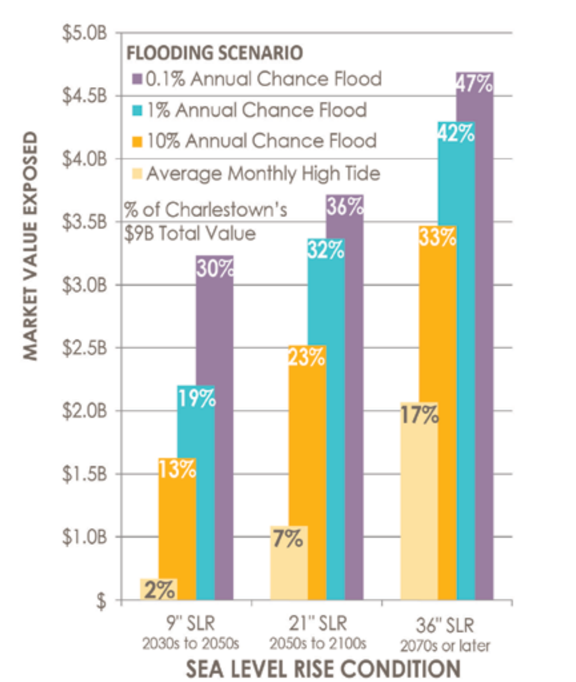
Charlestown faces risk from both coastal storms and rising sea levels. In the near term, the community can expect 20 structures exposed during monthly high tides and 140 structures exposed to flooding during a low-probability flood event (1 percent annual chance). As soon as the 2070s, over 50 percent of the land area is expected to be exposed to flooding from a low-probability flood event (1 percent annual chance event), with close to 700 structures potentially exposed. More than half of the exposed structures are residential or mixed-use in nature. In addition, as soon as the 2070s, over 130 existing structures are expected to be exposed to monthly high tides.

[5]These statistics do not include residential space in mixed-use buildings.

CHARLESTOWN BUILDING EXPOSURE



CHARLESTOWN MARKET VALUE EXPOSURE



While Charlestown is a smaller-scale neighborhood than some of the other focus areas considered, it is still in the top four focus areas for expected annualized structure and content losses in the near term, with $8.5M, compared to $62.6M in South Boston, $42.7M in Downtown, and $11.8M in East Boston.

RISK TO THE ECONOMY

As of 2014, there are over 12,200 jobs in Charlestown, and associated industries contribute over $2.5 billion of output (sales and revenues) into the city's economy annually. The Charlestown economy is well balanced, as no single industry comprises more than an 8 percent share of employment or output within the neighborhood.

Charlestown's economy is most vulnerable in medium- and long-term climate scenarios. Based on the neighborhood's current economy and building stock conditions, $8 million in annualized output loss and approximately 50 positions in annualized employment loss are expected toward the end of the century. Scientific research and development, accounting, and insurance-related services rank among top industries expected to be impacted. Losses have been calculated strictly based on expected flooding to structures, as opposed to egress and utility lines, and cascading loss of function impacts are not considered in the analysis.[6] In the second half of the century, the site of a current martial arts training center is expected to be heavily impacted by floodwaters and joins top industries expected to be affected by coastal storm events.

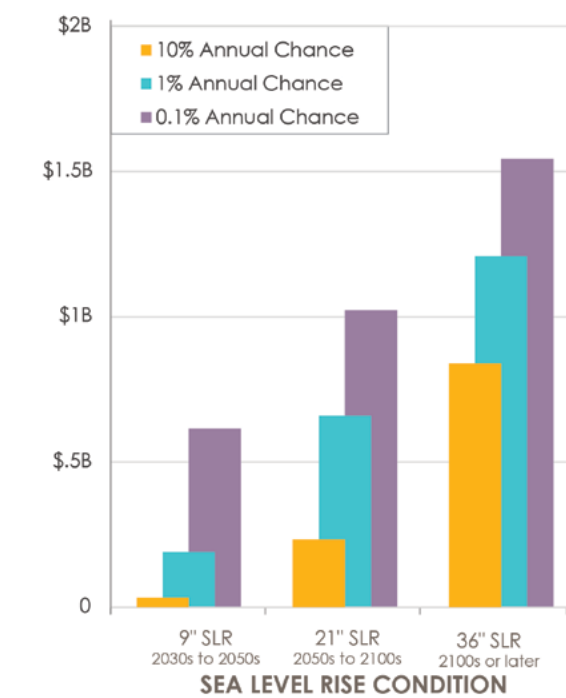
[6]More-detailed analysis would be required to quantify expected loss of function impacts to utilities and transportation outside of economic loss derived from direct physical damage to structures.

ECONOMIC RISK ASSUMPTIONS

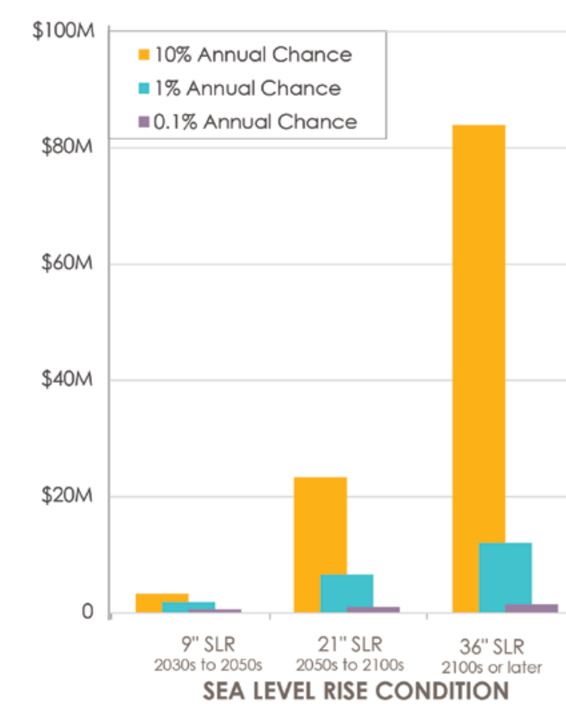
Job and output loss includes direct, indirect, and induced consequences of flood impacts. Direct results are impacts felt within a neighborhood, while indirect and induced results are those expected to be felt throughout Suffolk County as a result of changes in spending patterns. Results for both job and output losses are the sum of annualized values for the four flood frequencies analyzed for each sea level rise scenario. This represents a lower-bound estimate for several reasons. First, not all probabilistic events are considered. Second, the analysis assumes that all impacted businesses eventually reopen, though FEMA estimates that almost 40 percent of small businesses—and up to 25 percent of all businesses—never reopen after experiencing flood impacts. Third, only building areas directly impacted by floodwater are assumed to experience business interruption. This does not consider interruptions of businesses due to loss of power or utility functions. Finally, the analysis only considers existing populations, businesses, and buildings and does not include projections for future growth. Refer to the Appendix for a more detailed explanation of the exposure and consequence analysis.

INDUSTRY	ANNUALIZED LOSS OF ECONOMIC OUTPUT
Scientific research	$500,000
Accounting services	$400,000
Insurance agencies	$300,000
Fitness and recreation	$300,000
Restaurants	$200,000
All other industries	$6,700,000
Total	**$78,900,000**

CHARLESTOWN ECONOMIC LOSSES



CHARLESTOWN ANNUALIZED LOSSES



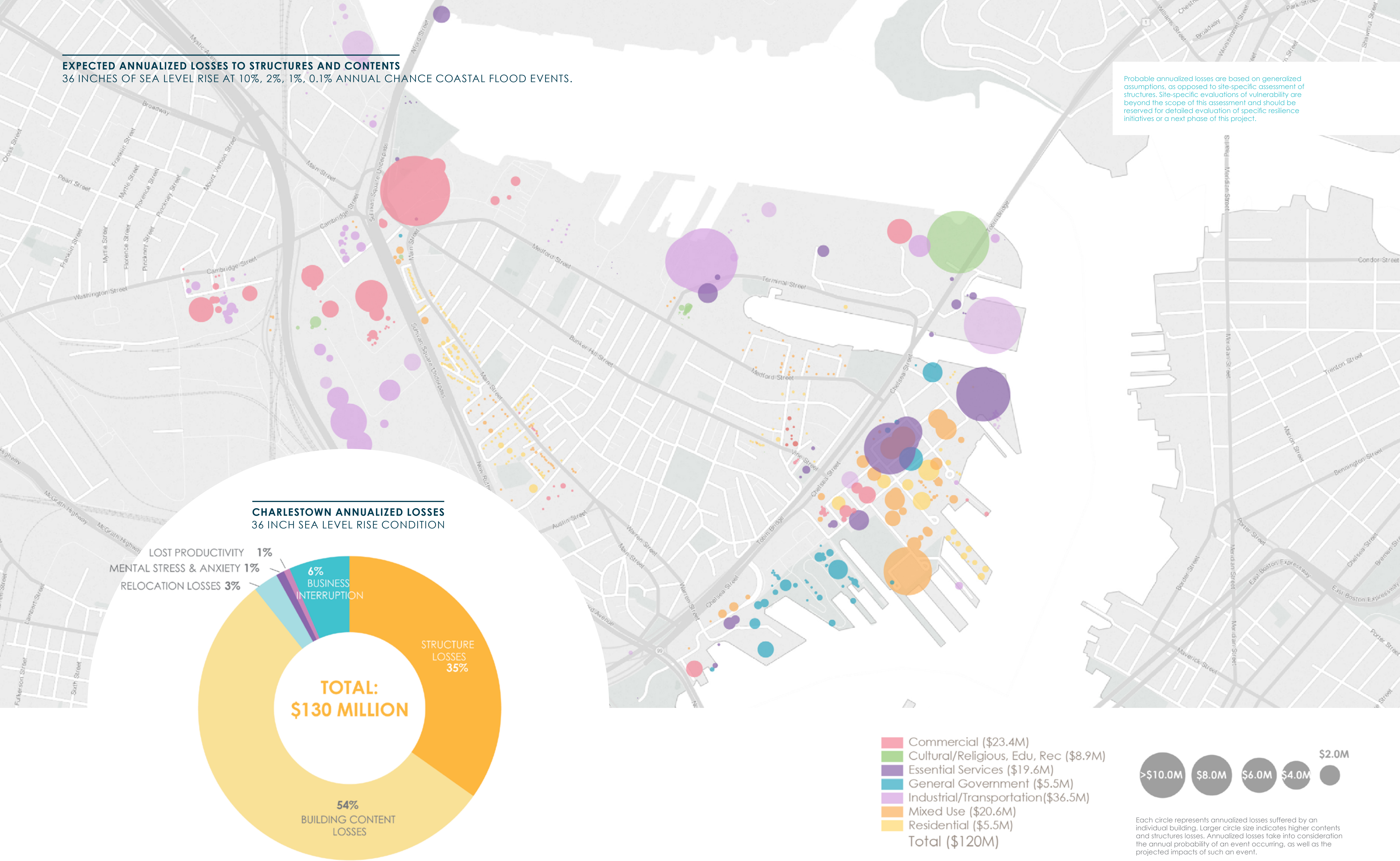
Charlestown is consistently expected to be among the top five focus areas most at risk to coastal flooding throughout the century in terms of land area, people, and buildings exposed.

Due to the prevalence of residential structures exposed to coastal flood impacts, Charlestown's economy is most vulnerable to medium- and long-term sea level rise scenarios.

EXPECTED ANNUALIZED LOSSES TO STRUCTURES AND CONTENTS
36 INCHES OF SEA LEVEL RISE AT 10%, 2%, 1%, 0.1% ANNUAL CHANCE COASTAL FLOOD EVENTS.

Probable annualized losses are based on generalized assumptions, as opposed to site-specific assessment of structures. Site-specific evaluations of vulnerability are beyond the scope of this assessment and should be reserved for detailed evaluation of specific resilience initiatives or a next phase of this project.

CHARLESTOWN ANNUALIZED LOSSES
36 INCH SEA LEVEL RISE CONDITION



- Commercial ($23.4M)
- Cultural/Religious, Edu, Rec ($8.9M)
- Essential Services ($19.6M)
- General Government ($5.5M)
- Industrial/Transportation($36.5M)
- Mixed Use ($20.6M)
- Residential ($5.5M)

Total ($120M)

>$10.0M $8.0M $6.0M $4.0M $2.0M

Each circle represents annualized losses suffered by an individual building. Larger circle size indicates higher contents and structures losses. Annualized losses take into consideration the annual probability of an event occurring, as well as the projected impacts of such an event.

CHARLESTOWN
APPLICATION OF RESILIENCE INITIATIVES

PROTECTED SHORES

DEVELOP LOCAL CLIMATE RESILIENCE PLANS TO SUPPORT DISTRICT-SCALE CLIMATE ADAPTATION

The City should develop a local climate resilience plan for Charlestown to support district-scale climate adaptation. The plan should include the following:

- **Community engagement** through a local climate resilience committee, leveraging existing community organizations, and efforts such as Boston Harbor Now's series of adaptation planning workshops in Charlestown.
- **Land-use planning for future flood protection systems,** including Flood Protection Overlay Districts in strategically important "flood breach points" identified below (see Potential Flood Protection Locations).
- **Flood protection feasibility studies,** evaluating district-scale flood protection, including at locations identified below (see Potential Flood Protection Locations).
- **Infrastructure adaptation planning** through the Infrastructure Coordination Committee. For Charlestown, the Massachusetts Department of Conservation and Recreation is a key partner, as it controls the New Charles River Dam.
- **Coordination with other plans**, including Imagine Boston 2030, GoBoston 2030, Special Planning Areas, and any potential Municipal Harbor Plan process.
- **Development of financing strategies and governance structures** to support district-scale adaptation.
- **Partnering with Cambridge and Somerville**, which are adjacent to Charlestown and connected to Charlestown by inundation pathways.

ESTABLISH FLOOD PROTECTION OVERLAY DISTRICTS AND REQUIRE POTENTIAL INTEGRATION WITH FLOOD PROTECTION

The Boston Planning and Development Agency (BPDA) should petition the Boston Zoning Commission to create new Flood Protection Overlay Districts in areas that are strategically important for potential future flood protection infrastructure (see Potential Flood Protection Locations below). Within a Flood Protection Overlay District, a developer would be required to submit a study of how a proposed project could be integrated into a future flood protection system; options may include raising and reinforcing the development site or providing room for a future easement across the site.

PRIORITIZE AND STUDY THE FEASIBILITY OF DISTRICT-SCALE FLOOD PROTECTION

To reduce the risk of coastal flooding at major inundation points, the City should study the feasibility of constructing district-scale flood protection at the primary flood entry points in Charlestown (see Potential Flood Protection Locations below for a preliminary identification of locations and potential benefits).

These feasibility studies should take place in the context of local climate resilience plans, featuring engagement with local community stakeholders, coordination with infrastructure adaptation, and considerations of how flood protection would impact or be impacted by neighborhood character and growth. Examples of prioritization criteria include the timing of flood risk, consequences for people and economy, social equity, financial feasibility, and potential for additional benefits beyond flood risk reduction.

POTENTIAL DISTRICT-SCALE FLOOD PROTECTION LOCATIONS[7]

See the District-Scale Flood Protection Systems Overview section (p.330) for a citywide perspective on district-scale flood protection. District-scale flood protection is only one piece of a multilayered solution that includes prepared and connected communities, resilient infrastructure, and adapted buildings.

In the near term, exposure to coastal flooding is limited to specific waterfront areas. As soon as the 2050s, combined flood protection at two key locations will become critical:

- **North Charlestown,** addressing a major flood entry point between I-93 and Bunker Hill Street, near Sullivan Square
- **The New Charles River Dam,** addressing future overtopping or flanking of the dam

SLR SCENARIO	DISTRICT SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD[8]
9" SLR (2030s–2050s)	None[9]
21" SLR (2050s–2100s)	North Charlestown and New Charles River Dam Locations combined
36" SLR (2070s or later)	North Charlestown and New Charles River Dam Locations combined

LOCATIONS

- **The North Charlestown Location** focuses on a major flood entry point at low ground between I-93 and Bunker Hill Street, near Sullivan Square. Potential flood protection solutions could include the following elements: permanent boundary protection along Bunker Hill Street; regraded and elevated streets near flood entry points; integrated flood protection and transportation improvements at Sullivan Square; a deployable barrier for the Route 99 trench; and temporary barriers at the intersection of Medford Street and Bunker Hill Street, the Engine 32/Ladder 9 entrance, and the Schrafft Center driveway.
- **The New Charles River Dam Location,** also described in the Downtown focus area section (see p. 216), addresses flooding by the Zakim Bridge / New Charles River Dam. Potential flood protection solutions could include a tide barrier across the mouth of Miller's River, a tide gate and connecting flood protection system just west of Littoral Way, or a deployable barrier across the railroad right-of-way connecting Charlestown and North Station.

[7] These preliminary coastal flood protection concepts build off of recommendations of the MassDOT-FHWA Pilot Project Report and are based on a high-level analysis of existing topography, rights-of-way, and urban and environmental conditions. Important additional factors, including existing drainage systems, underground transportation and utility structures, soil conditions, and zoning as well as any potential external impacts as a result of the project have not been studied in detail. As described in Initiatives 5-2 and 5-3 (pp. 106, 110), detailed feasibility studies, including appropriate public and stakeholder engagement, are required in order to better understand the costs and benefits of flood protection in each location.

[8] Additional flood protection may be required for flood events more severe than the 1 percent annual chance flood. See Appendix for more detailed information on expected effectiveness of flood protection systems, including analysis of additional flood protection locations and flood frequencies.

[9] Benefits of district-scale flood protection would be modest.

DETAILED CONSIDERATIONS

- **Modest near-term benefits for North Charlestown protection:** At 9 inches of sea level rise (SLR), flood protection at North Charlestown provides modest benefits in terms of economic losses avoided for the 1 percent annual chance event. To protect against near-term lower-probability events (0.1 percent annual chance event) in Charlestown, interventions at both North Charlestown and the New Charles River Dam may be needed,[10] as flooding from the Charles River and Boston Harbor proceed inland. At 21 inches of SLR or above, protection at Locations 5 and 7 will likely be necessary to provide protection beyond high-probability flood events (10 percent annual chance).
- **Industrial areas protected at North Charlestown:** Since the area benefitting from independent flood protection at North Charlestown without the New Charles River Dam protection is relatively small and primarily industrial, direct impact on population is likely limited. Evaluation of flood protection options may require consideration of possible brownfield mitigation and reduction of environmental contaminants.
- **Many neighborhoods benefit from dam flood protection:** Flood protection at the New Charles River Dam could simultaneously protect parts of northern Downtown, southern Downtown, Charlestown, the Charles River neighborhoods, and the South End and Roxbury.
- **Requirement for multiple protection locations in the late century:** A flood protection system at the New Charles River Dam is expected to provide significant protection in other neighborhoods against the 1 percent chance event until later in the century. However, to protect Charlestown from near-term to mid-century flooding, interventions at North Charlestown will likely be required.

[10] While it is expected that flood protection that would not be independently effective would have some effect on flood loss, this effect could be positive or negative, and understanding the extent of the effect would require more detailed evaluation. As such, any benefits or costs above the identified level of protection (the point beyond which the flood protection measure can no longer maintain independent effectiveness) have not been evaluated.

PREPARED & CONNECTED COMMUNITIES

CONDUCT AN OUTREACH CAMPAIGN TO PRIVATE FACILITIES THAT SERVE VULNERABLE POPULATIONS TO SUPPORT PREPAREDNESS AND ADAPTATION

The City should conduct outreach to managers of facilities in Charlestown that serve significant concentrations of vulnerable populations and are not required to have operational preparedness and evacuation plans under current regulations. Targeted facilities will include affordable housing complexes, substance abuse treatment centers, daycare facilities, food pantries, and small nonprofit offices, for example. An illustrative example of the type of facilities to which the City might conduct outreach include Bright Horizons Preschool at the Schrafft Center near Sullivan Square, which will be exposed to near-term damage from sea level rise and coastal flooding and access issues associated with near-term stormwater flooding.[11]

EXPAND BOSTON'S SMALL BUSINESS PREPAREDNESS PROGRAM

The City should reach out to small businesses in Charlestown exposed to stormwater flooding risk in the near term or coastal flooding risk under a 1 percent annual chance event at 9 inches of SLR to help them develop business continuity plans, evaluate insurance coverage needs, and identify low-cost physical adaptations. While Main Street, Charlestown's primary commercial corridor, is not exposed to flooding under a 1 percent annual chance event at 9 inches of SLR, there are 19 commercial buildings and 16 mixed-use buildings potentially hosting small businesses exposed.

[11]The City did not review the extent of existing preparedness planning as part of this study.

RESILIENT INFRASTRUCTURE

ESTABLISH INFRASTRUCTURE COORDINATION COMMITTEE

The Infrastructure Coordination Committee (ICC) should support coordinated adaptation planning for Charlestown's key infrastructure systems, including transportation, water and sewer, energy, telecommunications, and environmental assets. The City should support the MBTA in conducting a full asset-level vulnerability assessment of its system, including the Orange Line. While Charlestown's two Orange Line stops (Community College and Sullivan Square) are not directly exposed to coastal flooding at 9 inches of SLR under the 1 percent annual chance event, flooding of tunnels and stations in Downtown Boston could impede residents' ability to access jobs and essential services during flood events.

PROVIDE GUIDANCE ON PRIORITY EVACUATION AND SERVICE ROAD INFRASTRUCTURE TO THE ICC

The Office of Emergency Management should work with the Boston Transportation Department, Department of Public Works, and private utilities to provide guidance on critical roads to prioritize for adaptation planning, including those that are part of the city's evacuation network and are required to restore or maintain critical services. With 9 inches of SLR under a 1 percent annual chance flood event, Interstate 93, North Washington Street, and Alford Street will all be exposed to coastal flooding.

CONDUCT FEASIBILITY STUDIES FOR COMMUNITY ENERGY SOLUTIONS

The 2016 Boston Community Energy Study identified Charlestown's Main Street corridor as a potential location for an emergency microgrid, based on its concentration of critical facilities. The study also identified an area near Sullivan Square as a location for an Energy Justice microgrid. Small portions of the Main Street corridor site may be exposed to coastal flooding from the 1 percent annual chance event in the near term. The Sullivan Square site has a small area exposed under the 1 percent annual chance event with 9 inches of SLR, with exposure significantly increasing with 21 and 36 inches of SLR. The Environment Department can work with local stakeholders and utility providers to explore these locations.

ADAPTED BUILDINGS

PROMOTE CLIMATE READINESS FOR PROJECTS IN THE DEVELOPMENT PIPELINE

Upon amending the zoning code to support climate readiness (see Initiative 9-2, p.135), the Boston Planning and Development Agency (BPDA) should immediately notify all developers with projects in the development pipeline in the future floodplain that they may alter their plans in a manner consistent with the zoning amendments (e.g., elevating their first-floor ceilings without violating building height limits), without needing to restart the BPDA permitting process.

Currently, 17 residential and 8 commercial buildings are under construction or permitted in Charlestown, representing 267 additional housing units and 1.8 million square feet of new commercial space.

INCORPORATE FUTURE CLIMATE CONDITIONS INTO AREA PLANS AND ZONING AMENDMENTS

The Boston Planning and Development Agency should incorporate future climate considerations (long-term projections for extreme heat, stormwater flooding, and coastal and riverine flooding) into major planning efforts in Charlestown. These efforts include the planned transportation improvements to Rutherford Avenue and Sullivan Square and the redevelopment of the Bunker Hill Apartments.

ESTABLISH A CLIMATE READY BUILDINGS EDUCATION PROGRAM FOR PROPERTY OWNERS, SUPPORTED BY A RESILIENCE AUDIT PROGRAM

The City should develop and run a Climate Ready Buildings Education Program and a resilience audit program to inform property owners about their current and future climate risks and actions they can undertake to address these risks. To prepare for the most immediate risks, the City should prioritize audits for buildings with at least a 1 percent annual chance of exposure to coastal and riverine flooding in the near term, under 9 inches of sea level rise. In Charlestown, this includes 142 structures, with 17 percent of these consisting of residential and mixed-use buildings that house residents. A resilience audit should help property owners identify cost-effective, building-specific improvements to reduce flood risk, such as backflow preventers, elevation of critical equipment, and deployable flood barriers; promote interventions that address stormwater runoff or the urban heat island effect, such as green roofs or "cool roofs" that reflect heat; and encourage owners to develop operational preparedness plans and secure appropriate insurance coverage. The resilience audit program should include a combination of mandatory and voluntary, market-based and subsidized elements.

PREPARE MUNICIPAL FACILITIES FOR CLIMATE CHANGE

The Office of Budget Management should work with City departments to prioritize upgrades to municipal facilities in Charlestown that demonstrate high levels of vulnerability (in terms of the timing and extent of exposure), consequences of partial or full failure, and criticality (with highest priority for impacts on life and safety) from coastal flooding in the near term. In the near term, at 9 inches of SLR, EMS Station 5 will be exposed to flooding under the 1 percent annual flood event. The Charlestown Navy Yard, which is owned by the BPDA, is also exposed in the near term under monthly high tide. To address extreme heat risks, the City should prioritize backup power installation at municipal facilities that demonstrate high levels of criticality, including specific Boston Centers for Youth and Family and Boston Public School facilities that serve as emergency shelters.

Charles River Neighborhoods

The Charles River focus area consists of the neighborhoods that lie along the Charles River, including Beacon Hill, Back Bay, Fenway/Kenmore, and Allston/Brighton.

These neighborhoods have been grouped in a focus area because they are all expected to be exposed to flooding upon overtopping or flanking of the Charles River Dam.

Beacon Hill is located in the center of the Shawmut Peninsula. The area originally had three hills, two of which were leveled for Beacon Hill development. Construction of the Massachusetts State House occurred on the south slope in the 1790s. Residential squares were laid out according to the English model on the north slope.

The Back Bay neighborhood was created through fill during the late nineteenth century, adding 450 acres to the city. In 1814, the Boston and Roxbury Mill Corporation started building a dam blocking the tidal Back Bay, which extended from Brookline to Boston Common. The dam was economically unsuccessful, so Boston started filling in the tidal area in 1857, with the process completed by 1882. Back Bay became an elegant residential district, with blocks of three- to four-story brownstones organized along linear boulevards (Beacon Street, Marlborough Street, and Commonwealth Avenue), according to the Parisian model.

Fenway/Kenmore consists of land annexed from Brookline during the 1870s, as well as land filled in during the creation of the Back Bay Fens, the first park in Frederick Law Olmstead's Emerald Necklace. Olmstead designed the Fens, a set of constructed marshes, to address drainage and sanitary challenges associated with the Muddy River, which flows into the Charles River. While originally intended as a high-end residential district, Fenway/Kenmore subsequently attracted a large number of educational and cultural institutions. Fenway/Kenmore is connected to Allston/Brighton through a small strip of land along Brookline. Allston was annexed by Boston in 1874. During the 1800s, Allston/Brighton had significant industry, with stockyards, slaughterhouses, and meatpacking operations in Allston and northeast Brighton.

The Charles River focus area is unified by the Charles River. The first Charles River Dam was completed in 1910, converting it from a tidal estuary into a freshwater basin. The dam served to control the surface water level in the basin and upstream and to prevent seawater from the Boston Harbor from entering. The Charles River Esplanade was constructed at the same time to take advantage of the new recreational possibilities created by the basin. The Esplanade has been expanded and enhanced over time, with the present-day Hatch Shell added in 1940, although the Esplanade did lose some land to the construction of Storrow Drive in 1949. Storrow Drive, a high-speed access road, separates Beacon Hill, the Back Bay, and Fenway/Kenmore from the river. Soldiers Field Road does the same in Allston. The New Charles River Dam was completed in 1978.

Today, Beacon Hill and the Back Bay are among the most expensive residential neighborhoods in Boston. Charles Street, which extends from Massachusetts General Hospital to the Public Garden, is Beacon Hill's primary commercial corridor. Back Bay has commercial corridors along Newbury Street, Boylston Street, St. James Street, and Huntington Avenue. Fenway/Kenmore is a mixed-use district, with a diverse housing stock of brownstones, brick row housing, and newer apartment and condominium towers. Allston is also a mixed-use district that has experienced conversion of industrial uses to commercial, residential, and institutional uses over time and has also become a site of recent expansion by Harvard University.

Image courtesy of Sasaki

FLOOD PROGRESSION

In the near-term and through the middle of the century, buildings and infrastructure in the Charles River focus area have limited exposure to coastal flooding.

DEFINITIONS

Near term: Beginning 2030s, assumes 9 inches of sea level rise

Midterm: Beginning 2050s, assumes 21 inches of sea level rise

Long term: Beginning 2070s or later, assumes 36 inches of sea level rise

Exposure: Can refer to people, buildings, infrastructure, and other resources within areas likely to experience hazard impacts. Does not consider conditions that may prevent or limit impacts.

Vulnerability: Refers to how and why people or assets can be affected by a hazard. Requires site-specific information.

Consequence: Illustrates to what extent people or assets can be expected to be affected by a hazard, as a result of vulnerability and exposure. Consequences can often be communicated in terms of economic losses.

Annualized losses: The sum of the probability-weighted losses for all four flood frequencies analyzed for each sea level rise scenario. Probability-weighted losses are the losses for a single event times the probability of that event occurring in a given year.

*For a full list of definitions, refer to the Glossary on p. Y.

The Charles River neighborhoods are exposed to climate change impacts including heat, increased precipitation and stormwater flooding, and sea level rise and coastal and riverine flooding. Exposure to heat and stormwater flooding are addressed in the Citywide Vulnerability Assessment (see p.12), while exposure and consequences to coastal and riverine flood risk are further discussed in this section.

The primarily flood pathway in the Charles River neighborhoods is around and over the Charles River Dam. The New Charles River Dam was constructed in 1978 and is a complex sluice, lock, and pump system used to manage freshwater draining from the Charles River Basin, salt water from the Boston Harbor, and vessel navigation.[1] In the event of a storm, pumps are activated to proactively reduce the water level to accommodate for surge.

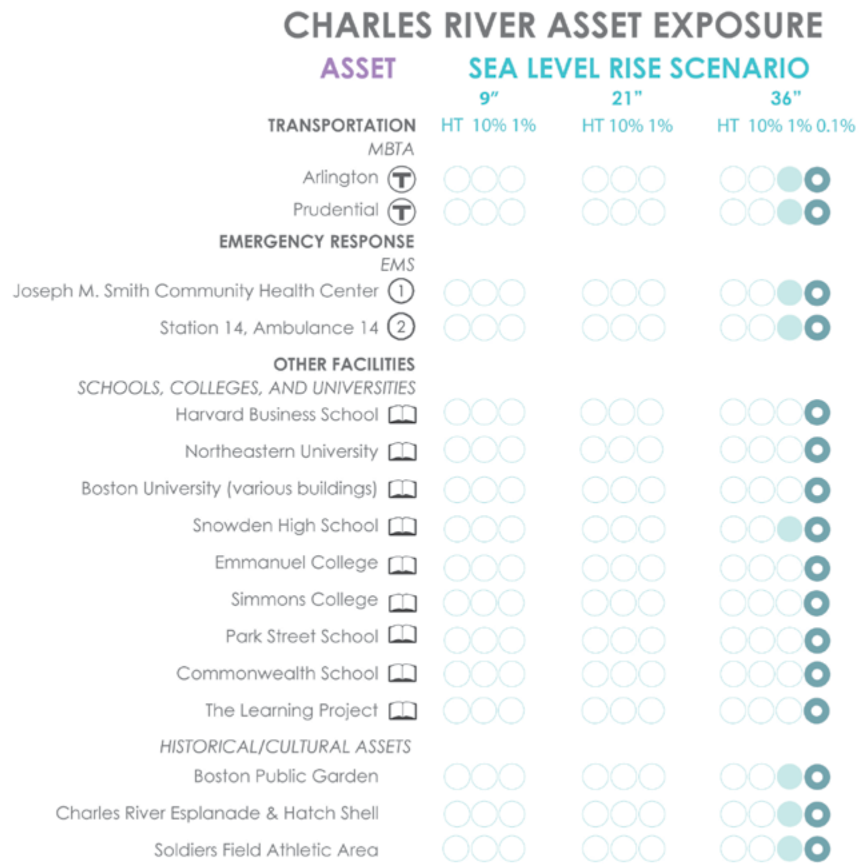
Because of the presence of the Charles River Dam, the Charles River neighborhoods have limited exposure to coastal flooding through the middle of the century. By the end of the century, Beacon Hill, Back Bay, Fenway/Kenmore, and Allston/Brighton, Charlestown, and Cambridge are expected to be exposed to flooding by flanking and overtopping of the dam for low-probability events. In low-probability flood events (1 percent annual chance) expected later in the century, flooding from the dam is expected to enter inland Boston through the Public Garden, contributing to the extensive flooding expected to collect in the South End from Fort Point Channel and Dorchester Bay during the same time frame (refer to the 36-inch flood exposure map). Very low-probability events (0.1 percent annual chance) are expected to have high enough storm surge that lands along the majority of the Charles River will be exposed to flooding.

Image courtesy of Sasaki

In the near term and through the middle of the century, buildings and infrastructure in the Charles River neighborhoods have or will have limited exposure to coastal flooding.

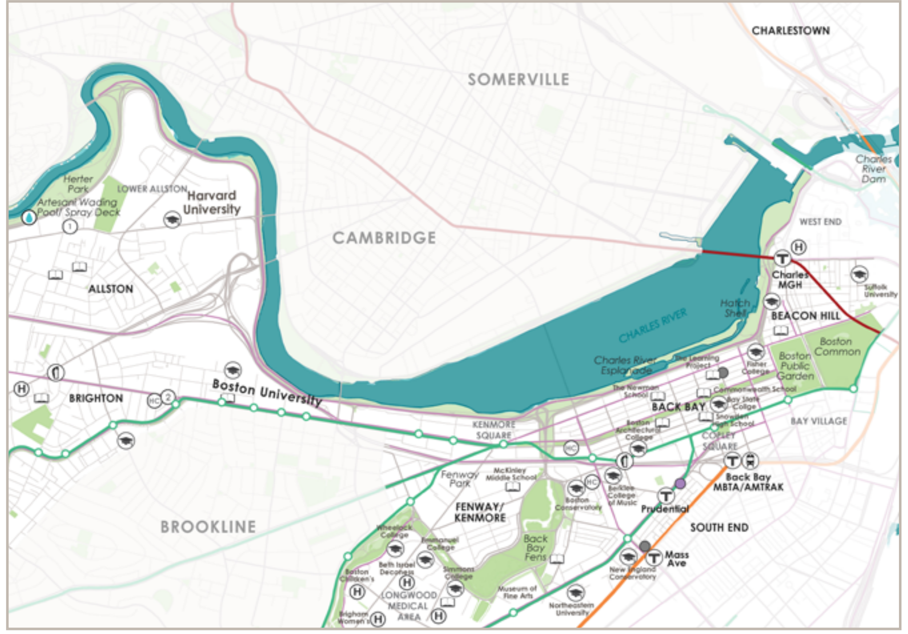
Of the Charles River neighborhoods, Allston has the greatest exposure in the near term due to low-lying open space. By the end of the century, the Charles River neighborhoods will begin to have some flood exposure to 1 percent annual chance events and may have hundreds of acres exposed to very low-probability events (0.1 percent chance).

[1] MassDOT FHWA Report citation: Bosma, Kirk, et. al. "MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery." Jun. 2015, https://www.massdot.state.ma.us/Portals/8/docs/environmental/SustainabilityEMS/Pilot_Project_Report_MassDOT_FHWA.pdf.

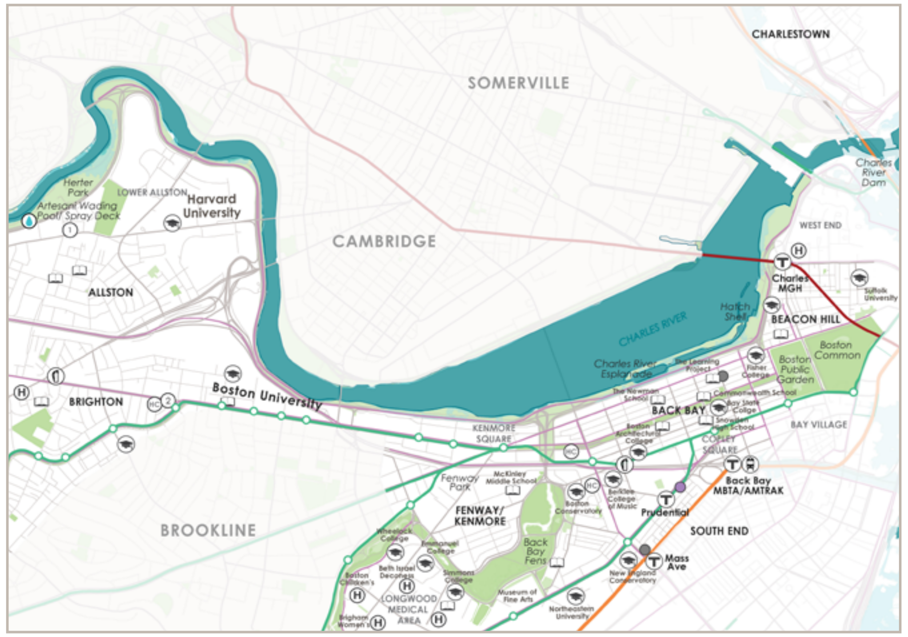


Later in the century, exposure of the Charles River neighborhoods to severe coastal storms with a low probability of occurrence increases significantly due to the possibility of overtopping and flanking of the Charles River Dam.

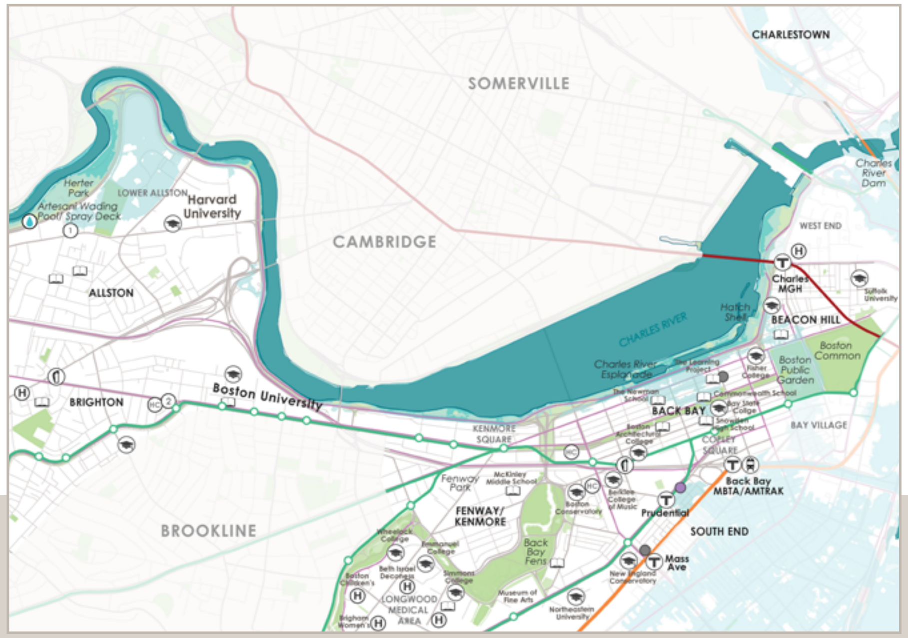
Climate resilience planning must consider that the primary flow pathway is over and around the Charles River dam. Adaptation of or around the dam would also benefit Charlestown, Downtown, and Cambridge.



9 INCHES SEA LEVEL RISE



21 INCHES SEA LEVEL RISE



36 INCHES SEA LEVEL RISE

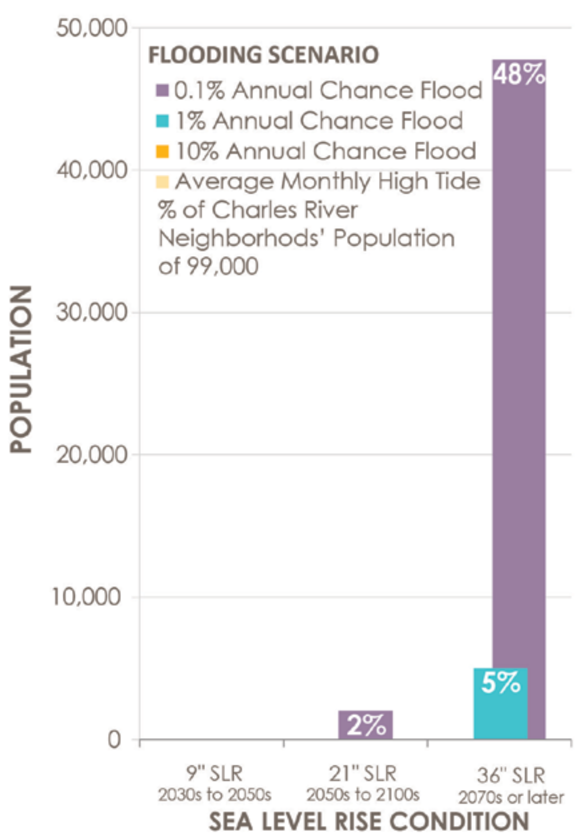
LEGEND

- Average Monthly High Tide
- 10% Annual Chance Storm
- 1% Annual Chance Storm
- Parks
- Roads
- Major Roads
- Major Tunnels
- Evacuation Route
- Evacuation Route Tunnels
- MBTA Blue Line
- MBTA Station
- MBTA B-Line Tunnel Entrance
- MBTA C-Line Tunnel Entrance
- MBTA D-Line Tunnel Entrance
- MBTA E-Line Tunnel Entrance
- College or University
- School
- Police Station
- Fire Station
- Hospital
- Health Care Facility
- EMS Station 14, Ambulance 14
- Jackson Mann Community Center
- BHA Public Housing
- Senior Housing
- Longterm Care Facility
- DCR Spray Deck or Pool

EXPOSURE

POPULATION & INFRASTRUCTURE

CHARLES RIVER POPULATION EXPOSURE



POPULATION & SOCIAL VULNERABILITIES

Residents of the Charles River neighborhoods comprise about 22 percent of Boston's overall population, or about 142,000 people. The Charles River neighborhoods are relatively affluent compared to the city as a whole; it has just one public housing development and 25 percent of the population in low- to no-income categories. Nevertheless, **Back Bay and Beacon Hill have among the highest percentage of people with a medical illness (42 percent) and older adults (12 percent) throughout Boston.**

Shelter needs in the Charles River neighborhoods are expected to be around 200 individuals for the area for the low-probability (1 percent annual chance) event later this century. Seven public emergency shelters are located within the Charles River neighborhoods, with the capacity to shelter 1,000 individuals. Only the Boston Arts Academy shelter will be exposed to the 0.1 percent annual chance event, which has a capacity of 151. The remaining shelters are not expected to be exposed to flood impacts and may be able to shelter some residents from other neighborhoods in an event. Unexposed colleges, universities, and hospitals in the Charles River neighborhoods may be able to provide shelter as well.

INFRASTRUCTURE

Transportation systems within the Charles River neighborhoods are not likely exposed to coastal flooding and sea level rise until later in the century. Even so, major impacts are only expected for low-probability events.

As soon as the 2050s, parts of Storrow Drive are expected to be exposed to low-probability storms. Later in the century, additional sections of Storrow Drive, as well as sections of Beacon Street and River Street in Back Bay and Beacon Hill, may be impacted by low-probability flood events (1 percent chance). Flooding along these roads will not only impact safe evacuation from the area, but potential damage and traffic interruptions may also affect crosstown connections and quick access to Downtown. Delivery of resources such as food supplies and research materials may also be disrupted in the case of flooded roads surrounding the campuses, in addition to student commutes to Boston University, Harvard's Business School and Stadium, and the Soldiers Field athletic area. Very low-probability flood events (0.1 percent annual chance) later in the century have the potential to impact Mass Pike, which may further limit transportation connections Downtown.

Portions of MBTA's Green Line within Back Bay and Beacon Hill, including the Arlington and Prudential T Stations, are exposed to flood impacts later in the century. The Green Line runs at grade for much of the western portion of its route and also has the potential to be interrupted by stormwater flooding between Packard's Corner and Harvard Avenue Stations. Service interruptions at the aforementioned stations could result in over 12,000 daily riders[2] needing alternative transportation, especially affecting those who use the Green Line to commute from Boston's inland neighborhoods to Downtown. Expected impacts to transportation patterns will grow significantly with a 0.1 percent chance event later in the century. Green Line exposure will extend from Back Bay and Beacon Hill into Fenway/Kenmore, while Red Line connections from Back Bay and Beacon Hill to Cambridge may also be affected by flooding.

Charles River emergency response assets are not expected to be exposed to flood impacts this century.

Areas adjacent to the Charles River neighborhoods with emergency response facilities exposed to coastal flood damage include Downtown, the South End, and northern Roxbury. If emergency response facilities in these areas are impacted by flooding, fire, police, and EMS stations in the Charles River neighborhoods may be called upon for support, in which case capacity, response times, and transportation routes between neighborhoods must be better understood.

Very low-probability events expected later in the century may impact many colleges and universities in the Charles River neighborhoods; colleges and universities provide the second-largest number of jobs in the area.

The Charles River neighborhoods are home to many well-known colleges and universities, including Boston University, portions of Harvard and Northeastern University, and other institutions associated with the Longwood Medical Area such as Simmons College and Emmanuel College. All of the aforementioned campuses have at least some portion exposed to the 0.1 percent chance event per the statistical expectation later in the century. Damages to campus assets or roads may not only disrupt class schedules and affect research, but the area's economy may suffer if there is prolonged interruption in operations. Site-specific reviews of each college and university asset are required to assess expected impacts.

[2]Based on 2014 MBTA ridership and service statistics. Number only captures station entries and does not include all passengers traveling on the line as is passes through the station.

EXPOSURE AND CONSEQUENCES

BUILDINGS AND ECONOMY

RISK TO BUILDINGS

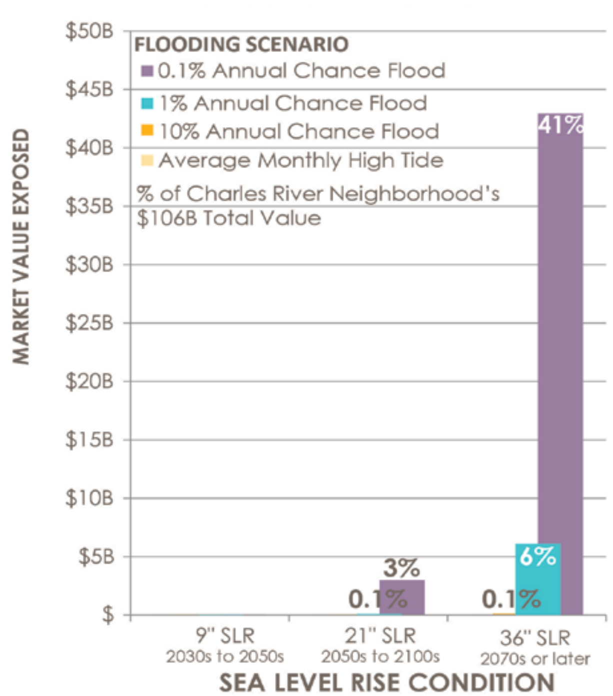
The Charles River neighborhoods are generally less exposed than other Climate Ready Boston focus areas in the near term and throughout the mid-century. Nevertheless, without mitigation, impacts may still be expected, particularly for the lower-probability flood events later this century.

The Charles River neighborhoods are not expected to experience structure and content damage until mid-century. Even so, damages may be comparatively low when considering impacts in other focus areas. As soon as the 2050s, approximately $13,000 in annualized structure and content losses are expected under the low-probability (1 percent annual chance) event. Mid-century losses are expected to be concentrated along the Charles River Esplanade.

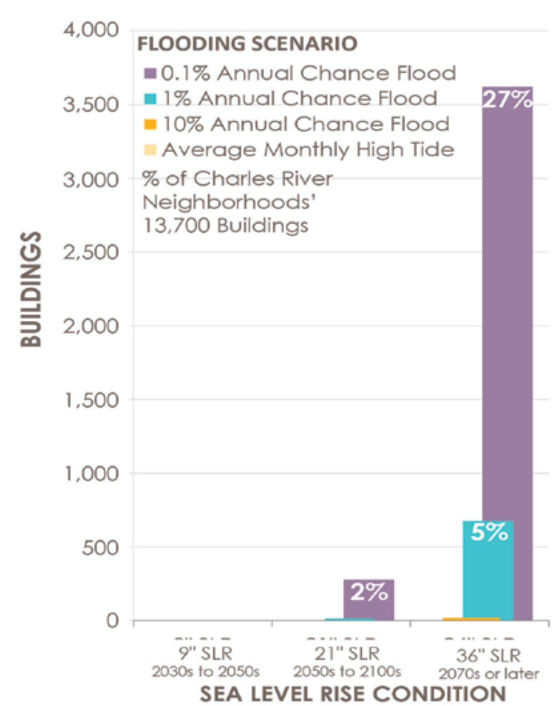
Structures exposed in the Charles River neighborhoods increase significantly from the 1 percent annual chance event (low probability) to the 0.1 percent annual chance event (very low probability) later in the century. Overall, nearly $15 million in annualized structure and contents losses could be expected as soon as the 2070s.

In the second half of the century, approximately 700 structures are expected to be exposed to the low-probability flood event (1 percent annual chance), with $4 million expected in annualized structure and contents losses. Most of these losses may be concentrated in Back Bay, with over 60 structures expected to be impacted in Allston and less than ten in Fenway. Very low-probability flood events (0.1 percent annual chance) expected as soon as the 2070s may present significant risk, with nearly 3,640 structures expected to be exposed. Considering all storm frequencies analyzed, nearly $15 million in annualized structure and contents losses are expected in the late century.

CHARLES RIVER REAL ESTATE MARKET VALUE EXPOSED



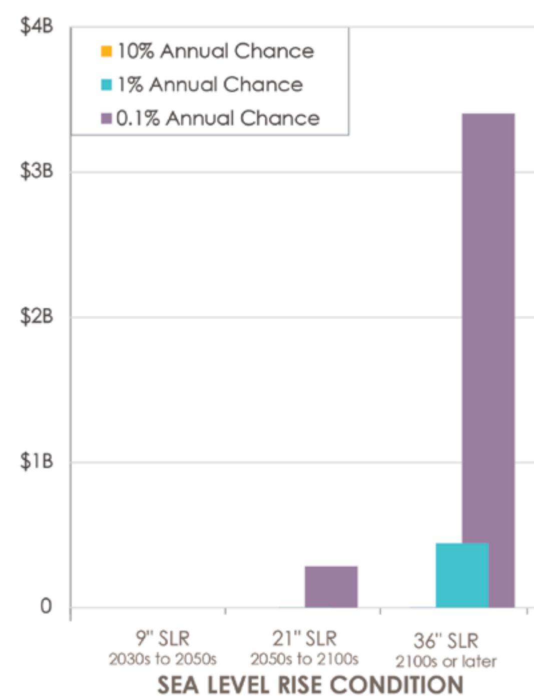
CHARLES RIVER BUILDING EXPOSURE



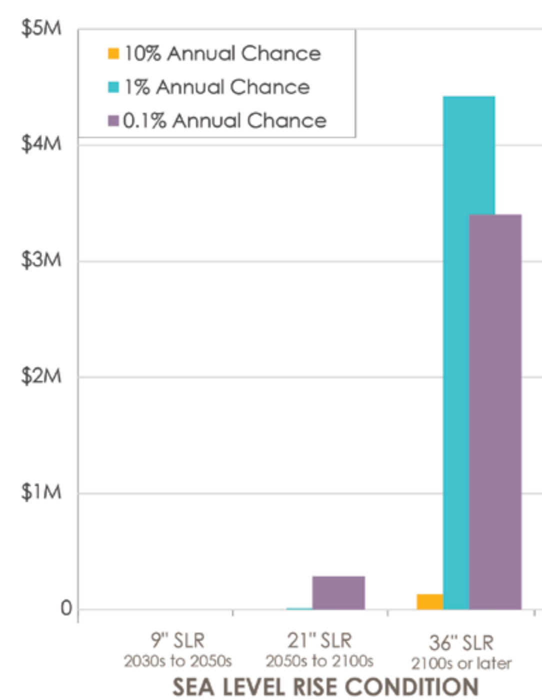
RISK TO THE ECONOMY

The Charles River neighborhoods contribute over 237,000 jobs and $46 billion in annual output (sales and revenues) to the Boston economy. Top industries in terms of employment are hospitals, restaurants, and colleges, universities, and professional schools due to the presence of the Longwood Medical Area and large institutions. Hospitals, real estate, insurance, and financial investment activities are the area's current top-producing industries when considering sales and revenues. I**n contrast to South Boston, many of the area's top industries are vulnerable to business interruption, as it is extremely difficult for many large institutions to operate remotely or relocate operations quickly in the event of a coastal storm.** Nevertheless, business interruption is not expected in the Charles River neighborhoods in the near-term, and mid-century business interruption is limited in comparison to other focus areas, though not insubstantial. In the second half of the century, the Charles River neighborhoods can expect close to $90,000 in annualized output losses due to expected flood damage to structures.[3] As soon as the 2070s, annualized output losses as a result of business interruption are expected to be around $6.3 million with approximately 40 annualized jobs lost. These estimates include interruption from businesses directly exposed to flood impacts, as well as the reverberations that impact may have throughout Suffolk County's economy.[4] **Industries expected to be most affected are the performing arts, restaurants, and entertainment and recreational facilities, likely due to the exposure at the Soldiers Field Athletic Area and other entertainment industries present along the Charles River.**

CHARLES RIVER ECONOMIC LOSSES



CHARLES RIVER ANNUALIZED LOSSES



ECONOMIC RISK ASSUMPTIONS

Job and output loss includes direct, indirect, and induced consequences of flood impacts. Direct results are impacts felt within a neighborhood, while indirect and induced results are those expected to be felt throughout Suffolk County as a result of changes in spending patterns. Results for both job and output losses are the sum of annualized values for the four flood frequencies analyzed for each sea level rise scenario. This represents a lower-bound estimate for several reasons. First, not all probabilistic events are considered. Second, the analysis assumes that all impacted businesses eventually reopen, though FEMA estimates that almost 40 percent of small businesses—and up to 25 percent of all businesses—never reopen after experiencing flood impacts. Third, only building areas directly impacted by floodwater are assumed to experience business interruption. This does not consider interruptions of businesses due to loss of power or utility functions. Finally, the analysis only considers existing populations, businesses, and buildings and does not include projections for future growth. Refer to the Appendix for a more detailed explanation of the exposure and consequence analysis.

INDUSTRY	ANNUALIZED LOSS OF ECONOMIC OUTPUT
Performers and Performing Arts Companies	$ 1,000,000
Restaurants	$ 630,000
Entertainment and Recreational Facilities, including sports centers, museums, and parks	$ 940,000
Real Estate	$ 730,000
All other industries	$ 2,900,000
Total	**$ 6,300,000**

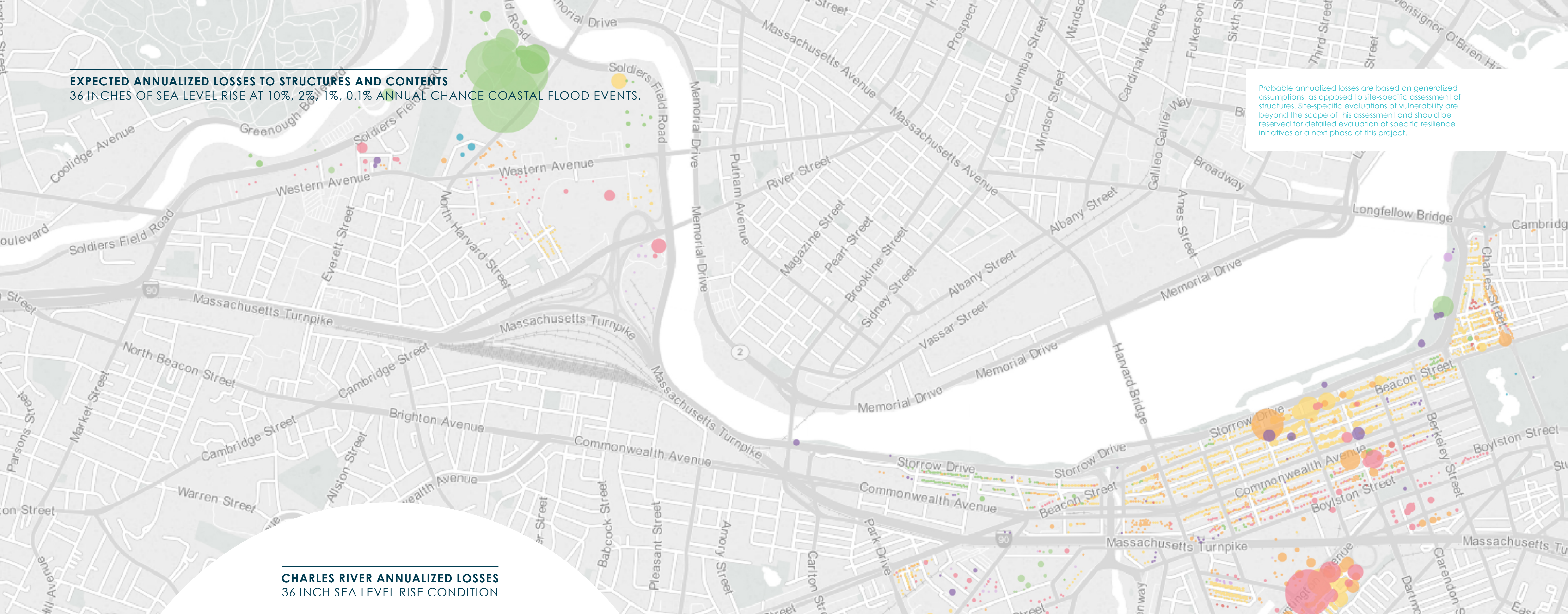
[3]Expected flood damages are calculated for the 10%, 2%, 1%, and 0.1% annual chance flood events only.

[4]Losses to particular industries are based on current development and economic activity in the area, and considering that South Boston is in a period of intense growth, may differ as development continues.

EXPECTED ANNUALIZED LOSSES TO STRUCTURES AND CONTENTS

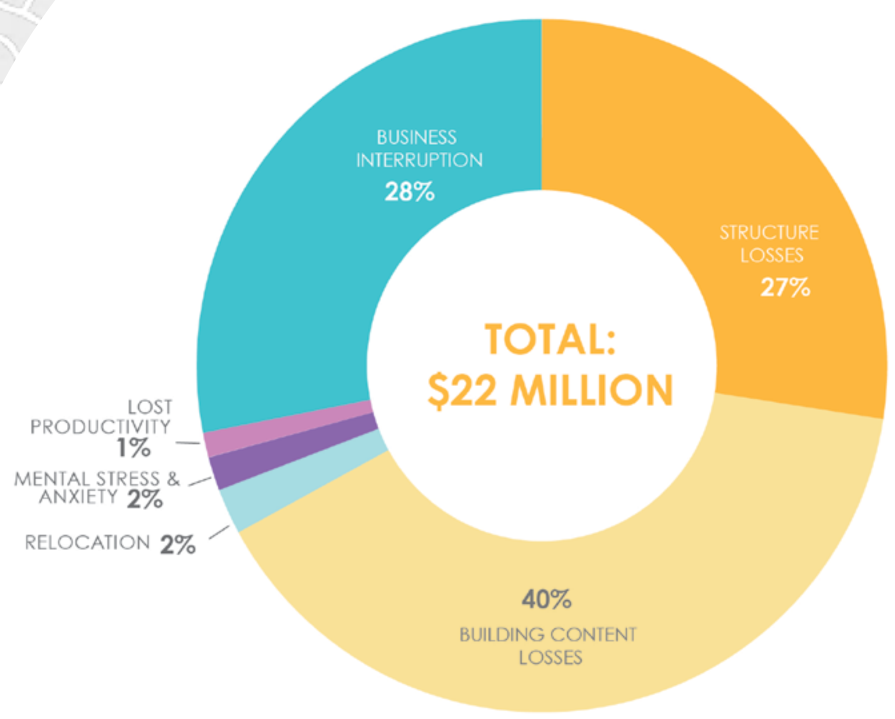
36 INCHES OF SEA LEVEL RISE AT 10%, 2%, 1%, 0.1% ANNUAL CHANCE COASTAL FLOOD EVENTS.

Probable annualized losses are based on generalized assumptions, as opposed to site-specific assessment of structures. Site-specific evaluations of vulnerability are beyond the scope of this assessment and should be reserved for detailed evaluation of specific resilience initiatives or a next phase of this project.



CHARLES RIVER ANNUALIZED LOSSES

36 INCH SEA LEVEL RISE CONDITION



- Commercial ($2.5M)
- Cultural/Religious, Edu, Rec ($6.1M)
- Essential Services ($.5M)
- General Government ($.1M)
- Industrial/Transportation($.145M)
- Mixed Use ($1.3M)
- Residential ($3.9M)

Total ($14.5M)

$2.0M $1.5M $1.0M $0.5M

Each circle represents annualized losses suffered by an individual building. Larger circle size indicates higher contents and structures losses. Annualized losses take into consideration the annual probability of an event occurring, as well as the projected impacts of such an event.

CHARLES RIVER NEIGHBORHOODS

APPLICATION OF RESILIENCE INITIATIVES

PROTECTED SHORES

PRIORITIZE AND STUDY THE FEASIBILITY OF DISTRICT-SCALE FLOOD PROTECTION

To reduce the risk of coastal flooding at major inundation points, the City should study the feasibility of constructing district-scale flood protection at the primary flood entry points for the Charles River neighborhoods (see Potential Flood Protection Locations below for a preliminary identification of locations and potential benefits). As described below, flood protection systems that would benefit these neighborhoods would likely be located by the New Charles River Dam, in South Boston, and in Dorchester.

These feasibility studies should feature engagement with local community stakeholders, coordination with infrastructure adaptation, and considerations of how flood protection would impact or be impacted by neighborhood character and growth. Examples of prioritization criteria include the timing of flood risk, consequences for people and the economy, social equity, financial feasibility, and potential for additional benefits beyond flood risk reduction.

POTENTIAL DISTRICT-SCALE FLOOD PROTECTION LOCATIONS[5]

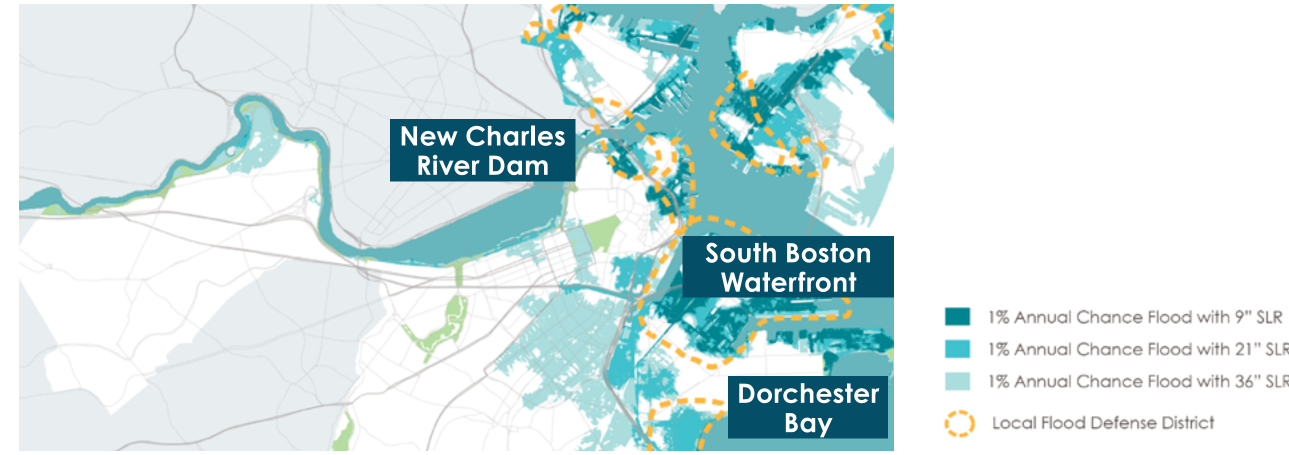
See District-Scale Flood Protection Systems section for a citywide perspective on district-scale flood protection. District-scale flood protection is only one piece of a multi-layered solution that includes prepared and connected communities, resilient infrastructure, and adapted buildings.

[5] These preliminary coastal flood protection concepts are based on a high-level analysis of existing topography, rights-of-way, and urban and environmental conditions. Important additional factors, including existing drainage systems, underground transportation and utility structures, soil conditions, zoning, as well as any potential external impacts as a result of the project have not been studied in detail. As described in Initiatives 5-2 and 5-3, detailed feasibility studies, including appropriate public and stakeholder engagement, are required in order to better understand the costs and benefits of flood protection in each location.

[6] Additional flood protection may be required for flood events more severe than the 1% annual chance flood. See Appendix for more detailed information on expected effectiveness of flood protection systems, including analysis of additional flood protection locations and flood frequencies.

[7] Benefits of district-scale flood protection would be modest.

[8] While it is expected that flood protection that would not be independently effective would have some effect on flood loss, this effect could be positive or negative, and understanding the extent of the effect would require more detailed evaluation. As such, any benefits or costs above the identified level of protection (the point beyond which the flood protection measure can no longer maintain independent effectiveness) have not been evaluated.



In the near term, coastal and riverine flood risk along the Charles River is modest and likely does not require district-scale flood protection.

Later in the century, combined flood protection at multiple locations will become critical:

- At the **New Charles River Dam,** addressing potential overtopping or flanking of the dam.
- At the **South Boston Waterfront,** addressing inland flood pathways originating from Fort Point Channel, Boston Harbor, and the Reserve Channel; and
- At **Dorchester Bay,** addressing inland flood pathways originating from the Old Harbor and Savin Hill Cove.

SLR SCENARIO	DISTRICT SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD[6]
9" SLR (2030s–2050s)	None[7]
21" SLR (2050s–2100s)	The New Charles River Dam
36" SLR (2070s or later)	The New Charles River Dam, South Boston Waterfront, and Dorchester Bay Locations combined

LOCATIONS

- **The New Charles River Dam location,** described in the Charles River and Downtown focus areas (see pp. 174, 216), addresses potential overtopping or flanking of the dam.
- **The South Boston Waterfront location,** described in the South Boston focus area (see p.282), addresses flood entry points along the edge of the district.
- **The Dorchester Bay location,** described in the Dorchester focus area (see p.194), addresses flood pathways from the Old Harbor and Savin Hill Cove.

DETAILED CONSIDERATIONS

- **Multiple neighborhoods protected:** The largest flood protection benefit for neighborhoods along the Charles River comes from protection at the New Charles River Dam. In addition, flood protection at the dam is expected to have near-term benefits for portions of Downtown and Charlestown.
- **Need for multiple alignments late century:** Flood protection at the dam alone will not protect against late-century flooding from Fort Point Channel, the Old Harbor, and Savin Hill Cove, for which interventions at the South Boston Waterfront and Dorchester Bay will be needed.

PREPARED & CONNECTED COMMUNITIES

CONDUCT AN OUTREACH CAMPAIGN TO PRIVATE FACILITIES THAT SERVE VULNERABLE POPULATIONS TO SUPPORT PREPAREDNESS AND ADAPTATION

In the long term, the City should conduct outreach to managers of facilities in the Charles River neighborhoods that serve significant concentrations of vulnerable populations and are not required to have operational preparedness and evacuation plans under current regulations. Targeted facilities should include affordable housing complexes, substance abuse treatment centers, daycare facilities, food pantries, small nonprofit offices, and others. The City should conduct outreach in the long term because there are no populations exposed under the 1 percent annual chance flood event until 36 inches of SLR, meaning that the Charles River neighborhoods has a longer adaptation window than other focus areas in the Boston. An illustrative example of the type of facilities to which the City could do outreach is the Bright Horizons Family Center, which will be exposed to damage later in the century.[9]

EXPAND BOSTON'S SMALL BUSINESS PREPAREDNESS PROGRAM

The City can reach out to small businesses in the Charles River neighborhoods exposed to stormwater flooding in the near term to help them develop business continuity plans, evaluate insurance coverage needs, and identify low-cost physical adaptations. The Charles River neighborhoods have roughly 160 commercial buildings exposed to stormwater flooding in the near term. In addition, the Brighton and the Allston Village Main Street Districts are expected to have isolated portions exposed to stormwater flooding in the near term and throughout the century. The Charles River neighborhoods do not have any small businesses exposed to coastal flooding during the 1 percent annual chance flood event with 9 inches of SLR.

[9]The City did not review the extent of existing preparedness planning as part of this study.

RESILIENT INFRASTRUCTURE

ESTABLISH INFRASTRUCTURE COORDINATION COMMITTEE

The Infrastructure Coordination Committee (ICC) should support coordinated adaptation planning for Charlestown's key infrastructure systems, including transportation, water and sewer, energy, telecommunications, and environmental assets. In the near term, the City should support the MBTA in conducting a full asset-level vulnerability assessment of its system. While the Charles River neighborhoods are not impacted by coastal and riverine flooding in the near term, flooding in Downtown Boston could reduce mobility for residents who depend on the Red, Green, and Orange Lines to access jobs and critical services in the area. In addition, in the later century under the 1 percent annual flood event, the Green Line will be exposed to coastal flooding, via the Arlington and Prudential Stations.

PROVIDE GUIDANCE ON PRIORITY EVACUATION AND SERVICE ROAD INFRASTRUCTURE TO THE ICC

The Office of Emergency Management should work with the Boston Transportation Department, Department of Public Works, and private utilities to provide guidance on critical roads to prioritize for adaptation planning, including those that are part of the City's evacuation network and are required to restore or maintain critical services. In particular, Storrow Drive will be exposed at 9 inches of SLR under the 1 percent annual chance flood event. Storrow Drive is an important cross-town route that runs along the Charles River Esplanade, becoming Soldiers Field Road to the west and David G. Mugar Way to the east.

CONDUCT FEASIBILITY STUDIES FOR COMMUNITY ENERGY SOLUTIONS

The 2016 Boston Community Energy Study identified four sites in the Charles River neighborhoods as potential locations for emergency microgrids, based on their concentration of critical facilities. The Environment Department can work with local stakeholders and utility providers to explore these locations. Two of the sites, adjacent to Fenway Park and Northeastern University, are exposed to coastal and riverine flooding for very low-probability events (0.1 percent annual chance) expected later in the century, with minimal and isolated exposure to stormwater flooding in the near term.

ADAPTED BUILDINGS

PROMOTE CLIMATE READINESS FOR PROJECTS IN THE DEVELOPMENT PIPELINE

Upon amending the zoning code to support climate readiness (see Initiative 9-2, p.135), the Boston Planning and Development Agency (BPDA) should immediately notify all developers with projects in the development pipeline in the future floodplain that they may alter their plans in a manner consistent with the zoning amendments (e.g., elevating their first-floor ceilings without violating building height limits), without needing to restart the BPDA permitting process. Currently, 121 residential and 45 commercial buildings are under construction or permitted in the Charles River neighborhoods, representing 4,511 additional housing units and 360,000 square feet of new commercial space.

INCORPORATE FUTURE CLIMATE CONDITIONS INTO AREA PLANS AND ZONING AMENDMENTS

The Boston Planning and Development Agency should incorporate future climate considerations (long-term projections for extreme heat, stormwater flooding, and coastal and riverine flooding) into major planning efforts in the Charles River neighborhoods.

ESTABLISH A CLIMATE READY BUILDINGS EDUCATION PROGRAM FOR PROPERTY OWNERS, SUPPORTED BY A RESILIENCE AUDIT PROGRAM

The City should develop and run a Climate Ready Buildings Education Program and a resilience audit program to inform property owners about their current and future climate risks and actions they can undertake to address these risks. A resilience audit should help property owners identify cost-effective, building-specific improvements to reduce flood risk, such as backflow preventers, elevation of critical equipment, and deployable flood barriers; promote interventions that address stormwater runoff or the urban heat island effect, such as green roofs or "cool roofs" that reflect heat; and encourage owners to develop operational preparedness plans and secure appropriate insurance coverage. The resilience audit program should include a combination of mandatory and voluntary, market-based and subsidized elements.

REPARE MUNICIPAL FACILITIES FOR CLIMATE CHANGE

To address extreme heat risks, the Office of Budget Management should work with City departments to prioritize backup power installation at municipal facilities that demonstrate high levels of criticality, including Boston Centers for Youth and Family and Boston Public School facilities that serve as emergency shelters. An illustrative example of the type of facility that the City might prioritize to protect the power supply within the Charles River neighborhoods against heat impacts is the Jackson Mann Community Center.

Dorchester

Dorchester is the largest neighborhood in Boston in terms of both population and geographic area. It is bounded by South Boston to the north, Dorchester Bay to the east, the Neponset River to the south, and Mattapan and Roxbury to the west.

Dorchester was founded in 1630 and remained a predominately agricultural community for 200 years, although there was some waterfront industrial activity, especially in the Lower Mills area along the Neponset River and at Commercial Point. During the nineteenth century, Dorchester became a country retreat for wealthier Boston households, who built estates and second homes. In 1845, the Old Colony Railroad opened, with stations along Crescent Avenue (near the current JFK/U Mass Station), Savin Hill, and Harrison Square (near the current Fields Corner Station), thereby connecting Boston and Plymouth, Massachusetts. In 1870, Boston fully annexed Dorchester, and commercial and residential development accelerated. Supported by new streetcar and municipal water service, Dorchester's population increased from only 12,000 residents in 1870 to 150,000 by the 1920s.

From 1950 to 1980, Dorchester experienced disinvestment. In the 1950s, the Old Colony line was closed, and construction of the Southeast Expressway (I-93), which separated Dorchester's residential areas to the west from the waterfront, was completed. In 1964, the Columbia Point public housing complex, which included approximately 1,500 low-income units, opened. By the 1980s, the complex was in such disrepair that it was turned over to a private firm for redevelopment. However, there was some modest institutional investment during this time period, with University of Massachusetts Boston Harbor Campus opening on Columbia Point in 1974 and the John F. Kennedy Presidential Library and Museum in 1979.

Today, Dorchester consists of a number of distinct residential neighborhoods, anchored by commercial districts, including Uphams Corner, Fields Corner, and Codman Square. Dorchester has benefitted from the recent expansion of the Fairmount Line, which runs from Downtown to Readville, with three new stations in Dorchester (Newmarket, Four Corners/Geneva Avenue, and Talbot Avenue). The City is planning transit-oriented development along the Fairmount Line. In addition, the University of Massachusetts Boston is planning a significant expansion at Columbia Point on the former Bayside Exposition Center site.

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FLOOD PROGRESSION

DEFINITIONS

Near term: Beginning 2030s, assumes 9 inches of sea level rise

Midterm: Beginning 2050s, assumes 21 inches of sea level rise

Long term: Beginning 2070s or later, assumes 36 inches of sea level rise

Exposure: Can refer to people, buildings, infrastructure, and other resources within areas likely to experience hazard impacts. Does not consider conditions that may prevent or limit impacts.

Vulnerability: Refers to how and why people or assets can be affected by a hazard. Requires site-specific information.

Consequence: Illustrates to what extent people or assets can be expected to be affected by a hazard, as a result of vulnerability and exposure. Consequences can often be communicated in terms of economic losses.

Annualized losses: The sum of the probability-weighted losses for all four flood frequencies analyzed for each sea level rise scenario. Probability-weighted losses are the losses for a single event times the probability of that event occurring in a given year.

*For a full list of definitions, refer to the Glossary in the Appendix.

In the second half of the century, large areas of Dorchester will be exposed to high-probability flooding (10 percent annual chance). During this time frame, coastal flooding in Dorchester will be most prominent from Dorchester Bay near Joseph Moakley Park and along the Neponset River.

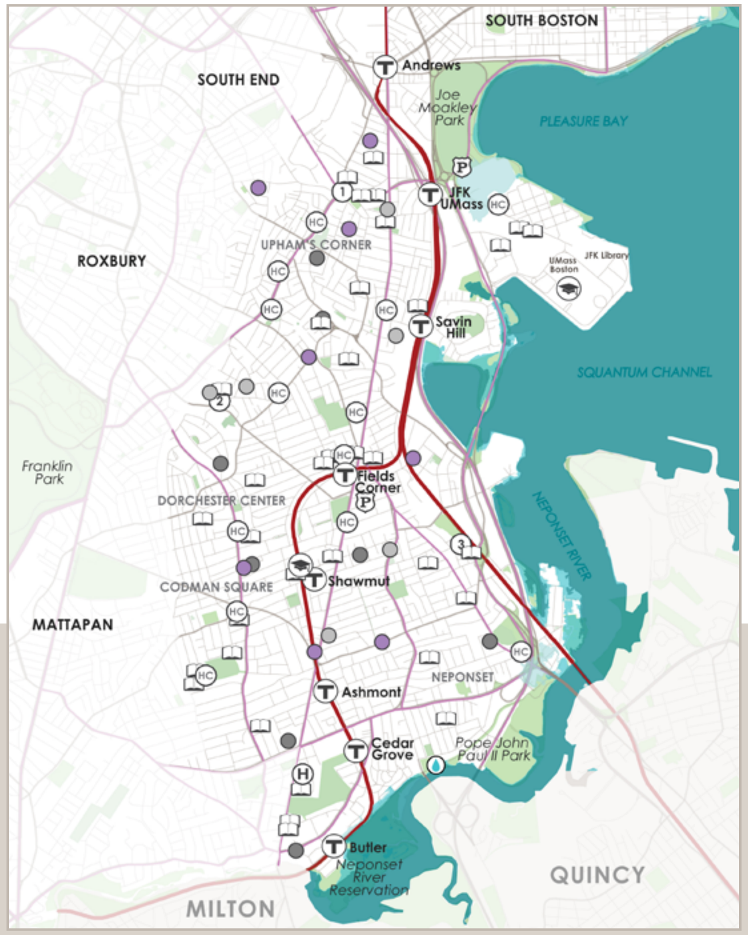
Dorchester is exposed to climate change impacts including heat, increased precipitation and stormwater flooding, and sea level rise and coastal and riverine flooding. Exposure to heat and stormwater flooding are addressed in the Citywide Vulnerability Assessment (see p.12), while exposure and consequences to coastal and riverine flood risk are further discussed in this section

In the near term and in the second half of the century, exposure to coastal flooding is primarily due to the low waterfront edge along Dorchester

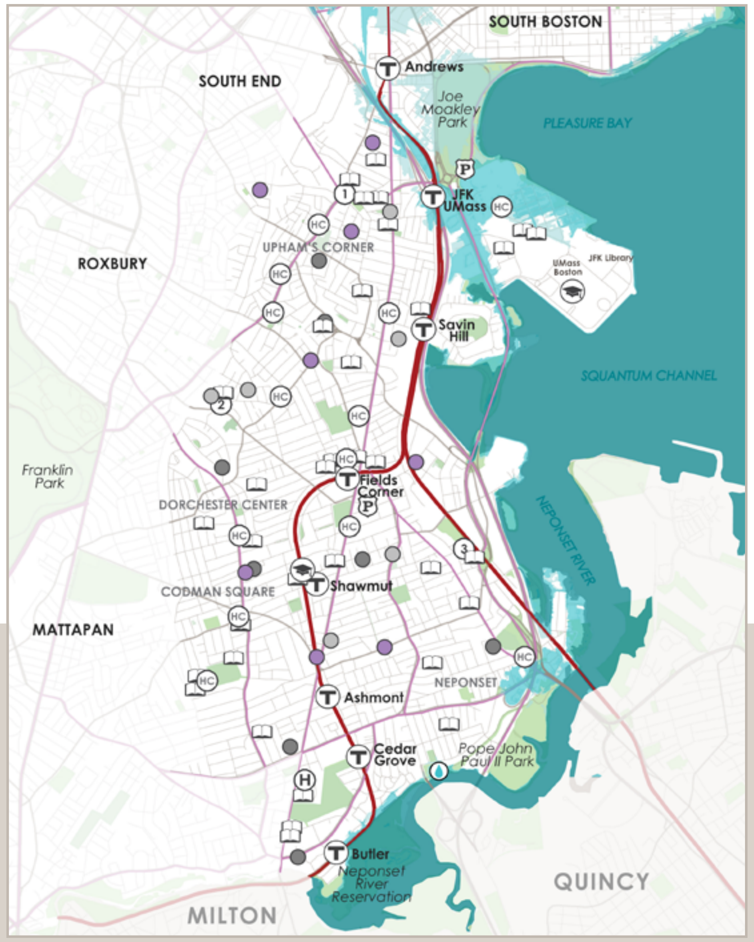
LEGEND

- Average Monthly High Tide
- 10% Annual Chance Storm
- 1% Annual Chance Storm
- Parks
- Roads
- Major Roads
- Major Tunnels
- Evacuation Route
- Evacuation Route Tunnels
- MBTA Blue Line
- MBTA Station
- College or University
- School
- Police Station
- Fire Station
- Healthcare Center
- Cleveland Community Center
- Holland Community Center
- Leahy-Holloran (Murphy) Community C
- Senior Housing
- Longterm Care Facility
- BHA Public Housing

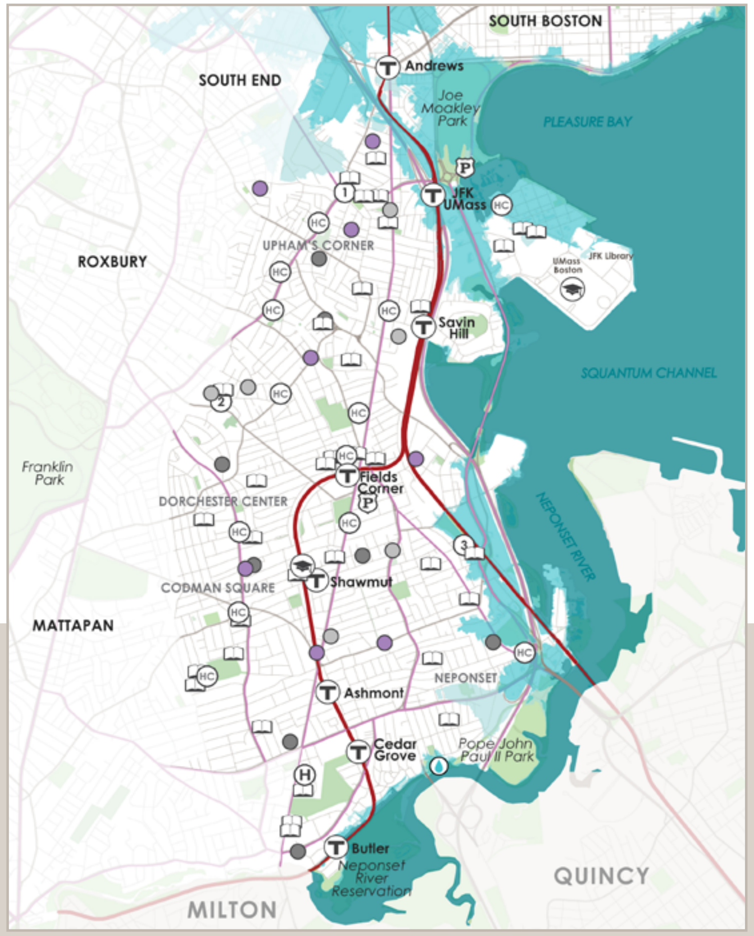
9 INCHES SEA LEVEL RISE



21 INCHES SEA LEVEL RISE



36 INCHES SEA LEVEL RISE



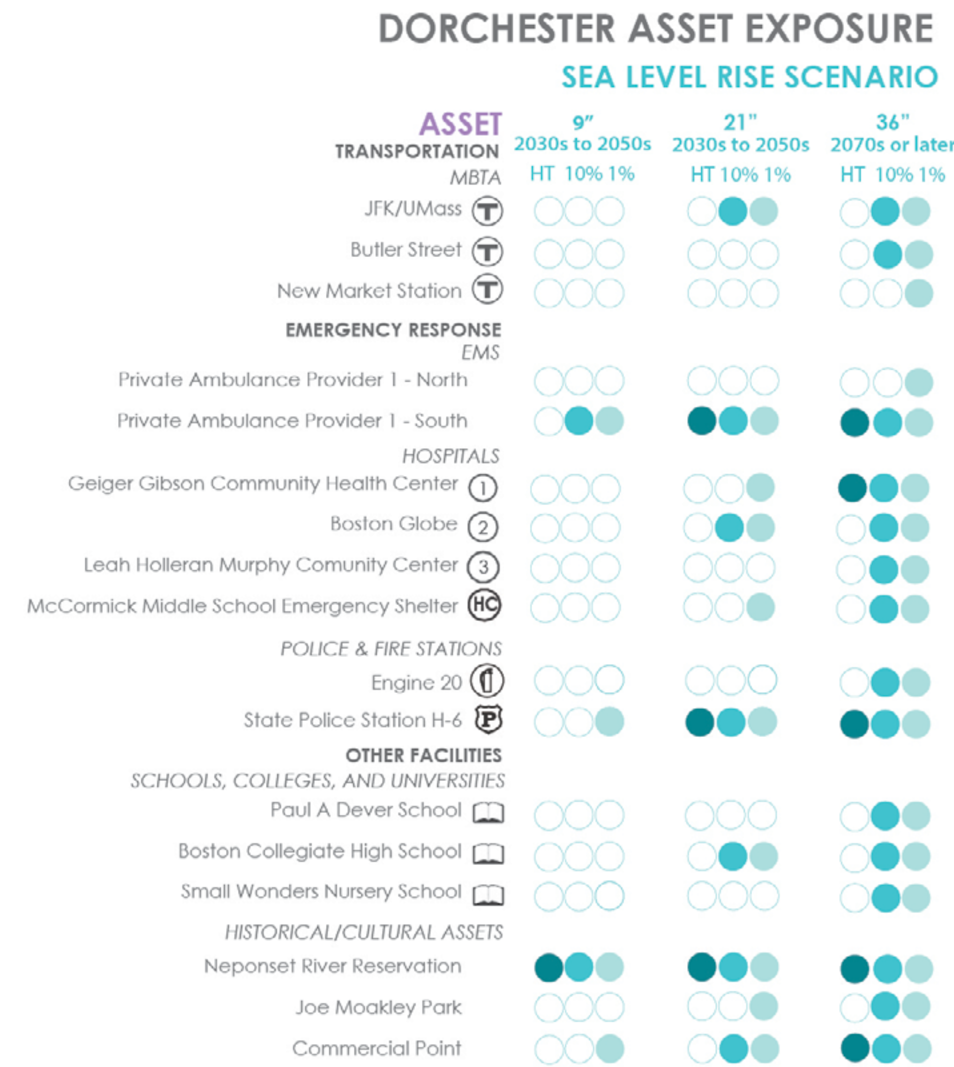
Bay and the Neponset River. Though exposure is largely limited in the near term, approximately 10 percent of the land areas in Dorchester have a high probability of flooding as soon as the 2050s (10 percent annual chance). Areas around Joseph Moakley Park are additionally exposed to low-probability flood events (1 percent annual chance) as soon as the 2050s.

In the late century, Dorchester exposure will change significantly, with large areas exposed to high-probability flood events (10 percent annual chance). More critically, **in the late century, Northern Dorchester is expected to become a flood pathway to South Boston, the South End, and Roxbury.** Areas around Joseph Moakley Park, created using fill in the late 1800s, tend to be low lying, leading to the exposure in Dorchester and surrounding areas.

The topography around Joseph Moakley Park and I-93 is low lying, potentially allowing floodwaters to propagate inland. Flood protection solutions targeted toward this area in northern Dorchester may provide benefits in South Boston, the South End, and Roxbury.

The greatest concentration of land area exposed is on the northern end of Dorchester, due to coastal flooding from Dorchester Bay through Joseph Moakley Park.

In the late century, flooding from Dorchester Bay will extend from Dorchester into South Boston, the South End, and Roxbury.



EXPOSURE

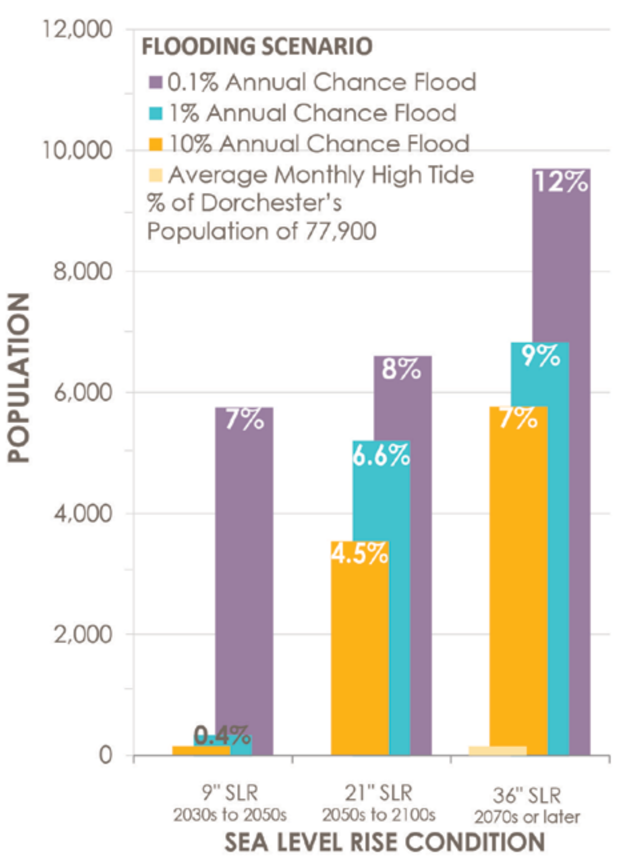
POPULATION & INFRASTRUCTURE

POPULATION AND SOCIAL VULNERABILITIES

There are about 87,000 residents in Dorchester, about 14 percent of Boston's overall population. In total, 24 percent of Dorchester households have children, compared to 17 percent citywide. Dorchester also has a diverse population that is 72 percent people of color, compared to 52 percent citywide.

Approximately 6,820 people live in housing that is projected to be at risk in a low-probability flood scenario (1 percent annual chance) as soon as the 2070s, generating need for shelter beds for an estimated 750 individuals. Seven public emergency shelters are located within Dorchester and have the capacity for 1,000 individuals. McCormick Middle School, located on Columbia Point, is northern Dorchester's only emergency shelter, and as soon as the 2050s, it will be exposed to low-probability flood events (1 percent annual chance). If this shelter is impacted by flooding, all roads leading out of Columbia Point are also expected to be flooded, potentially isolating residents in the northern portion of Dorchester without shelter. As soon as the 2070s, the Leahy Holloran Community Center will also be exposed to high-probability flood events (10 percent annual chance), which would reduce the shelter capacity by an additional 140 individuals.

DORCHESTER POPULATION EXPOSURE



INFRASTRUCTURE

Damage to exposed roads and the MBTA Red Line could isolate Columbia Point from the rest of Dorchester and impact transportation connections to North Quincy.

Within this century, all of Dorchester's evacuation routes, including I-93 South, Morrissey Boulevard, Neponset Avenue, and Gallivan Boulevard, will be exposed to coastal flooding and sea level rise. In the near term, portions of Morrissey Boulevard near the Dorchester Bay Basin and the Neponset Avenue/I-93 South junction are exposed to high-probability flood events (1 percent annual chance). As soon as the 2050s, all of Morrissey Boulevard, as well as sections of I-93 South in the same area, will be exposed to high-probability flood events (10 percent annual chance). Road closures due to flood damage could isolate Columbia Point from the rest of Dorchester, impacting a major university (University of Massachusetts Boston) and three K–12 schools, affecting delivery of resources into the area, and affecting major transportation links between Downtown Boston, Dorchester, and the South Shore.

In the second half of the century, the MBTA Red Line JFK/UMass Station will be exposed to high-probability flood events, meaning that approximately 8,000 riders may need alternative transportation options. In addition, portions of the Fairmount commuter rail line in South Boston are exposed to high-probability storms, potentially limiting the transportation options of those who commute from Dorchester to South Boston or Downtown using this line. As soon as the 2070s, sections of the Fairmount line in northern Dorchester and the Newmarket Station will be exposed to flooding. Low- to no-income populations that might depend disproportionally on public transportation may also be disproportionally affected by the impacts for coastal flooding and sea level rise in the mid- to late century.

Dorchester's emergency response facilities are exposed to sea level rise and coastal flood impacts throughout the century.

Private ambulance service providers have two facilities located in the Dorchester neighborhood. In the near term, one facility is exposed to flood impacts due to high-probability storms (10 percent annual chance). As soon as the 2050s, it will be exposed to monthly tides. If the station is damaged or has reduced response capacity, then the remaining station may be expected to cover the service area. As soon as the 2070s, the remaining station will become exposed to flooding from low-probability events (1 percent annual chance).

In the near term, the Boston State Police Station H-6 will be exposed to low-probability storm events, while the Engine 20 Fire Station will be exposed to high-probability storm events (10 percent annual chance) as soon as the 2070s and may require support from other stations in the neighborhood.

Commercial Point is exposed to low-probability storms in the near term. This is not expected to disrupt distribution of liquid natural gas to and from National Grid's storage tank.

Commercial Point, nested between Dorchester Bay and the Neponset River, is home to a liquid natural gas (LNG) storage tank, solar panels, and a commercial marina. National Grid's LNG storage tank on Commercial Point is elevated to provide protection against storm surge and is not expected to be exposed to flood impacts this century. Though other portions of Commercial Point and surface roads that connect the plant inland are exposed to flooding in the near term, National Grid has operational contingencies and plans in place to keep the natural gas plant operational. The solar power–generating facility on Commercial Point is not expected to be exposed to coastal flooding during this century but may be at risk of wind damage during storm events.

EXPOSURE AND CONSEQUENCES
BUILDINGS AND ECONOMY

RISK TO BUILDINGS

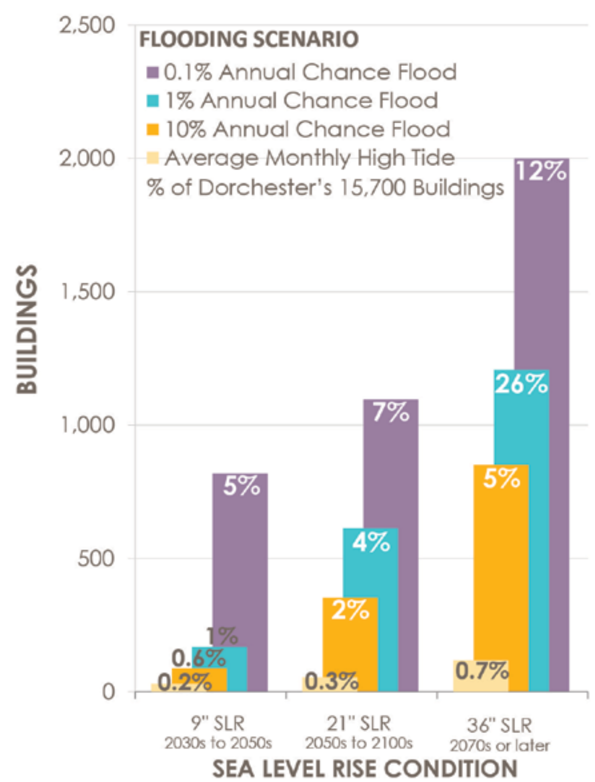
In the near term, close to 170 structures in Dorchester can expect some level of flooding from a low-probability event (1 percent annual chance) leading to $6 million in annualized direct physical damage costs to structures and their contents. Loss is expected to be concentrated most heavily in commercial (including office) and industrial uses. Exposure to high tide is also significant, with over 30 structures exposed in the near term (about $11 million in real estate market value).

As soon as the 2070s, close to 4,500 of Dorchester's structures can expect some level of flooding from a low-probability event resulting in direct physical damage costs of $86 million. Over half of all annualized losses expected in the late century are attributed to commercial and office buildings averaging three stories tall.

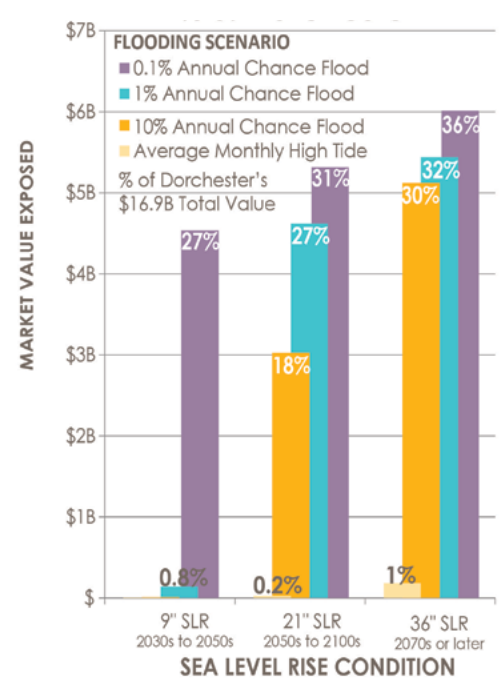
In addition, close to 120 structures (close to $200 million in real estate market value) are expected to be exposed to high tide later in the century. Also expected to be exposed to high tide later in the century is the former Bayside Exposition Center, where University of Massachusetts Boston has planned expansion and redevelopment.

Close to 4,500 structures can expect some level of flooding from a low-probability event in the late century.

DORCHESTER BUILDING EXPOSURE



DORCHESTER MARKET VALUE EXPOSURE



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Over $200 million in current real estate market value is expected to be exposed to high tides in the late century.

RISK TO THE ECONOMY[1]

Dorchester provides Boston with close to 35,000 jobs and over $7 billion in annual output. Top employers in the community include public education, hospitals, and grocers, though no one industry seems to dominate. The economy is heavily service oriented. As with other service-oriented neighborhood economies, restaurants are expected to be most heavily impacted in a flood event, particularly considering expected loss of employment. This is expected to be the case throughout the century. As soon as the 2070s, coastal flood impacts to Dorchester are expected to result in 110 annualized jobs lost and about $15 million in annualized output loss to the current Boston economy. Restaurants are expected to comprise roughly 40 percent of job loss and 20 percent of output loss. Restaurants tend to employ low- to moderate-income personnel, and business interruption to such assets can exacerbate impacts to already vulnerable populations.

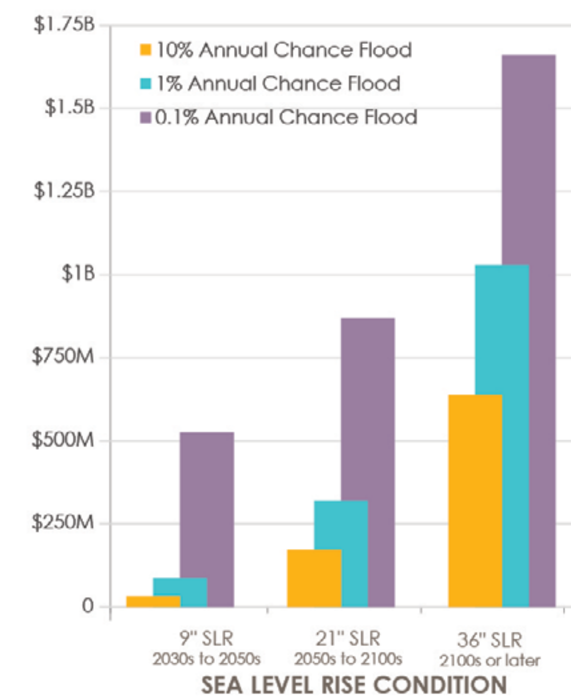
[1] Economic data is provided at the zip code level. One of the South Dorchester zip codes overlaps with Mattapan. As such, the base economic data, and thus annual jobs and output production, for South Dorchester includes some of Mattapan. This is expected to have minimal impact on calculated results, which are based on average output and employment by industry per square foot within neighborhood zip codes.

ECONOMIC RISK ASSUMPTIONS

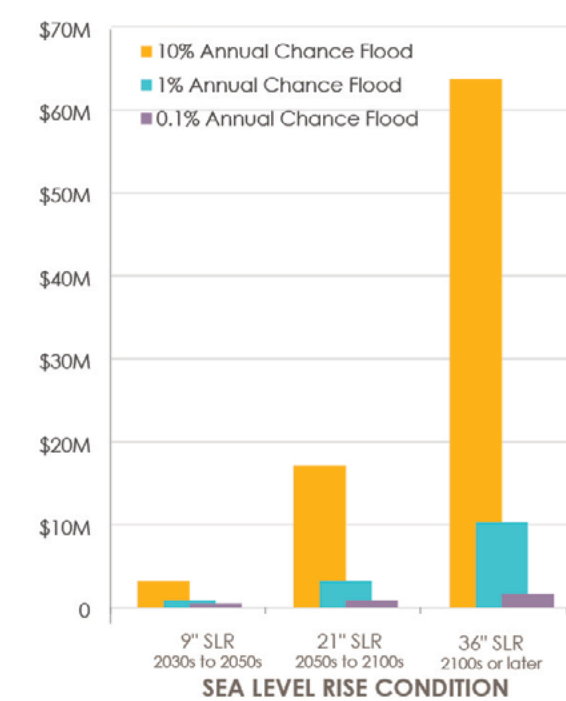
Job and output loss includes direct, indirect, and induced consequences of flood impacts. Direct results are impacts felt within a neighborhood, while indirect and induced results are those expected to be felt throughout Suffolk County as a result of changes in spending patterns. Results for both job and output losses are the sum of annualized values for the four flood frequencies analyzed for each sea level rise scenario. This represents a lower-bound estimate for several reasons. First, not all probabilistic events are considered. Second, the analysis assumes that all impacted businesses eventually reopen, though FEMA estimates that almost 40 percent of small businesses—and up to 25 percent of all businesses—never reopen after experiencing flood impacts. Third, only building areas directly impacted by floodwater are assumed to experience business interruption. This does not consider interruptions of businesses due to loss of power or utility functions. Finally, the analysis only considers existing populations, businesses, and buildings and does not include projections for future growth. Refer to the Appendix for a more detailed explanation of the exposure and consequence analysis.

INDUSTRY	ANNUALIZED LOSS OF ECONOMIC OUTPUT
Restaurants	$3,200,000
Real Estate	$1,400,00
Recreation facilities, including bowling centers, sports centers, and parks	$790,000
Wholesale trade and retail	$1,700,000
All other industries	$7,900,000
Total	**$14,900,000**

DORCHESTER ECONOMIC LOSSES



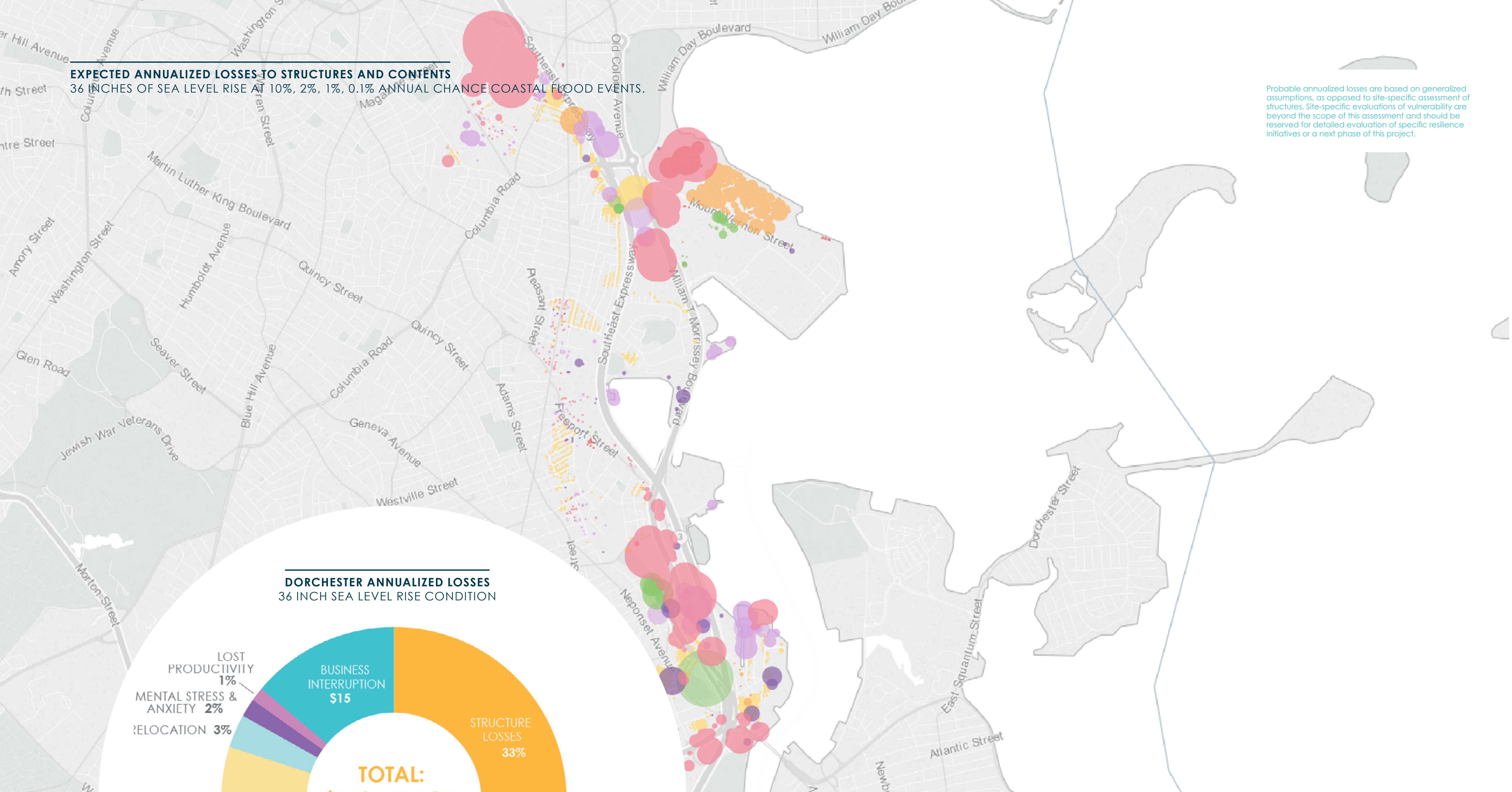
DORCHESTER ANNUALIZED LOSSES



Direct physical damages to structures are expected to be heavily concentrated in commercial and office use buildings.

EXPECTED ANNUALIZED LOSSES TO STRUCTURES AND CONTENTS

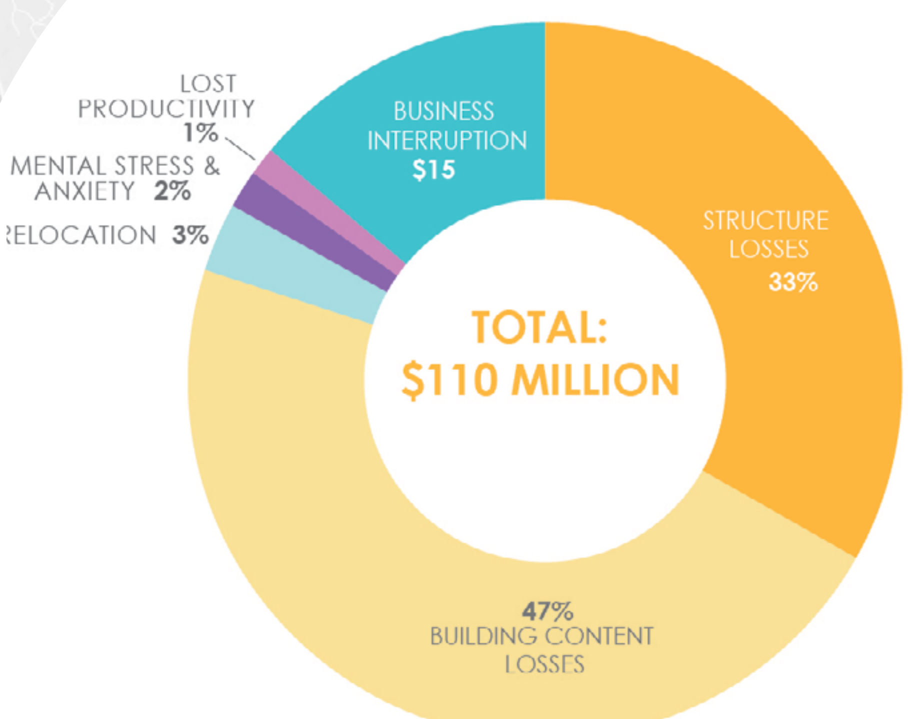
36 INCHES OF SEA LEVEL RISE AT 10%, 2%, 1%, 0.1% ANNUAL CHANCE COASTAL FLOOD EVENTS.



Probable annualized losses are based on generalized assumptions, as opposed to site-specific assessment of structures. Site-specific evaluations of vulnerability are beyond the scope of this assessment and should be reserved for detailed evaluation of specific resilience initiatives or a next phase of this project.

DORCHESTER ANNUALIZED LOSSES

36 INCH SEA LEVEL RISE CONDITION



- Commercial ($48.7M)
- Cultural/Religious, Edu, Rec ($8.3M)
- Essential Services ($2.4M)
- General Government ($0M)
- Industrial/Transportation($14.01M)
- Mixed Use ($10.5M)
- Residential ($8.6M)

Total ($93M)

$4.0M $3.0M $2.0M $1.0M

Each circle represents annualized losses suffered by an individual building. Larger circle size indicates higher contents and structures losses. Annualized losses take into consideration the annual probability of an event occurring, as well as the projected impacts of such an event.

DORCHESTER

APPLICATION OF RESILIENCE INITIATIVES

PROTECTED SHORES

DEVELOP LOCAL CLIMATE RESILIENCE PLANS TO SUPPORT DISTRICT-SCALE CLIMATE ADAPTATION

The City should develop a local climate resilience plan for Dorchester to support district-scale climate adaptation. The plan should include the following:

- **Community engagement** through a local climate resilience committee, leveraging existing local organizations and efforts.
- **Land-use planning for future flood protection systems,** including Flood Protection Overlay Districts in strategically important "flood breach points" identified below (see Potential Flood Protection Locations).
- **Flood protection feasibility studies,** evaluating district-scale flood protection, including at locations identified below (see Potential Flood Protection Locations).
- **Infrastructure adaptation planning** through the Infrastructure Coordination Committee. For Dorchester, key partners include the Department of Conservation and Recreation, which controls Morrissey Boulevard, and the Boston Parks and Recreation Department, which controls Joseph Moakley Park.
- **Coordination with other plans,** including Imagine Boston 2030, GoBoston 2030, Special Planning Areas, the Morrissey Boulevard redesign, the Joseph Moakley Park master plan, and any potential Municipal Harbor Plan process.
- **Development of financing strategies and governance structures** to support district-scale adaptation.

ESTABLISH FLOOD PROTECTION OVERLAY DISTRICTS AND REQUIRE POTENTIAL INTEGRATION WITH FLOOD PROTECTION

The Boston Planning and Development Agency (BPDA) should petition the Boston Zoning Commission to create new Flood Protection Overlay Districts in areas that are strategically important for potential future flood protection infrastructure (see Potential Flood Protection Locations below). Within a Flood Protection Overlay District, a developer would be required to submit a study of how a proposed project could be integrated into a future flood protection system; options may include raising and reinforcing the development site or providing room for a future easement across the site.

PRIORITIZE AND STUDY THE FEASIBILITY OF DISTRICT-SCALE FLOOD PROTECTION

To reduce the risk of coastal flooding at major inundation points, the City should study the feasibility of constructing district-scale flood protection at the primary flood entry points in Dorchester (see Potential Flood Protection Locations below for a preliminary identification of locations and potential benefits).

These feasibility studies should take place in the context of local climate resilience plans, featuring engagement with local community stakeholders, coordination with infrastructure adaptation, and considerations of how flood protection would impact or be impacted by neighborhood character and growth. Examples of prioritization criteria include the timing of flood risk, consequences for people and economy, social equity, financial feasibility, and potential for additional benefits beyond flood risk reduction.

POTENTIAL DISTRICT-SCALE FLOOD PROTECTION LOCATIONS[2]

See District-Scale Flood Protection Systems section for a citywide perspective on district-scale flood protection. District-scale flood protection is only one piece of a multi-layered solution that includes prepared and connected communities, resilient infrastructure, and adapted buildings.

In the near term, coastal flood risk Dorchester is limited to very low-probability, severe events and likely does not require district-scale flood protection.

As soon as the 2050s, combined flood protection at multiple locations will be critical:

- At **Dorchester Bay,** addressing inland flood pathways originating from the Old Harbor and Savin Hill Cove
- At the **South Boston Waterfront,** addressing inland flood pathways originating from Fort Point Channel, Boston Harbor, and the Reserve Channel
- At the **New Charles River Dam,** addressing potential overtopping or flanking of the dam

SLR SCENARIO	DISTRICT SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD[3]
9" SLR (2030s–2050s)	None[4]
21" SLR (2050s–2100s)	The South Boston Waterfront and Dorchester Bay locations combined
36" SLR (2070s or later)	The New Charles River Dam, South Boston Waterfront, and Dorchester Bay locations combined

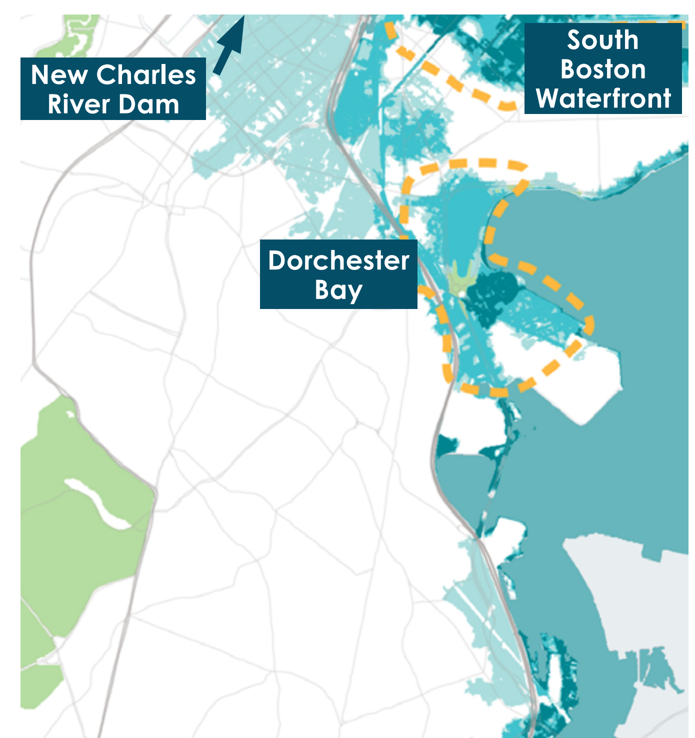
[2]These preliminary coastal flood protection concepts are based on a high-level analysis of existing topography, rights-of-way, and urban and environmental conditions. Important additional factors, including existing drainage systems, underground transportation and utility structures, soil conditions, and zoning as well as any potential external impacts as a result of the project have not been studied in detail. As described in Initiatives 5-2 and 5-3 (see pp. 106,110), detailed feasibility studies, including appropriate public and stakeholder engagement, are required in order to better understand the costs and benefits of flood protection in each location.

[3]Additional flood protection may be required for flood events more severe than the 1% annual chance flood. See Appendix for more detailed information on expected effectiveness of flood protection systems, including analysis of additional flood protection locations and flood frequencies.

[4]Benefits of district-scale flood protection would be modest.

LOCATIONS

- The **Dorchester Bay location** focuses on flood pathways along the Old Harbor and Savin Hill Cove. Potential flood protection solutions could include a landscaped berm or full elevation of Joseph Moakley Park, a waterside alignment along William Day Boulevard, an alignment along Harbor Point, a landscaped berm or alignment running along the waterfront through Old Harbor Park, and an alignment along Old Colony Avenue.
- The **New Charles River Dam location,** described in the Charles River and Downtown focus areas (see pp. 174, 216), addresses potential overtopping or flanking of the dam.
- The **South Boston Waterfront location,** described in the South Boston focus area (see p.282), addresses flood entry points along the edge of the district.



DETAILED CONSIDERATIONS

- **Independently effective in the near term:** Dorchester Bay flood protection is expected to be independently effective in protecting portions of Dorchester in the near term until the 0.1 percent annual chance event. Nevertheless, impacts to Dorchester residents are modest in the near term, as the 1 percent annual chance event and higher probability events are not expected to affect residential buildings.
- **Multiple protection locations required in the second half of the century:** Dorchester and areas in South Boston surrounding Joseph Moakley Park may be exposed to flooding from Fort Point Channel as soon as the 2050s. At this point, flood protection at the South Boston Waterfront may be required to supplement flood protection at Dorchester Bay. The combination of flood protection at these two locations will benefit Dorchester, South Boston, Downtown, the South End, and even northern Roxbury. Later in the century, interventions at the New Charles River Dam will be required to protect the aforementioned neighborhoods against the 1 percent annual chance event.

PREPARED & CONNECTED COMMUNITIES

CONDUCT AN OUTREACH CAMPAIGN TO PRIVATE FACILITIES THAT SERVE VULNERABLE POPULATIONS TO ENSURE THAT THEY ENGAGE IN EMERGENCY PREPAREDNESS AND ADAPTATION PLANNING.

The City should conduct outreach to managers of facilities in Dorchester that serve significant concentrations of vulnerable populations and are not required to have operational preparedness and evacuation plans under current regulations. Targeted facilities should include affordable housing complexes, substance abuse treatment centers, daycare facilities, food pantries, small nonprofit offices, and others. Illustrative examples of the types of facilities to which the City should conduct outreach are the Harbor Point mixed-income development and Columbia Point Infant Toddler Daycare. These facilities will be exposed to damage from mid-century sea level rise and coastal flooding, in addition to access issues related to stormwater flooding in the near term.[5]

EXPAND BOSTON'S SMALL BUSINESS PREPAREDNESS PROGRAM

The City should reach out to small businesses in Dorchester exposed to stormwater flooding risk in the near term or coastal flooding risk at 9 inches of SLR to help them develop business continuity plans, evaluate additional insurance coverage needs, and identify low-cost physical adaptations. In Dorchester, there are 34 commercial or mixed-use buildings that could host small businesses exposed to flooding under 1 percent annual chance flood event with 9 inches of SLR. Furthermore, three Main Street districts, Upham's Corner, Bowdoin/Geneva, and Field's Corner, are expected to have isolated portions exposed to stormwater flooding in the near term and throughout the century.

[5] The City did not review the extent of existing preparedness planning as part of this study.

RESILIENT INFRASTRUCTURE

ESTABLISH INFRASTRUCTURE COORDINATION COMMITTEE ADAPTATION PLANNING.

The Infrastructure Coordination Committee (ICC) should support coordinated adaptation planning for Dorchester's key infrastructure systems, including transportation, water and sewer, energy, telecommunications, and environmental assets. In the near term, the City will support the MBTA in conducting a full asset-level vulnerability assessment of its system, including the Red Line. The JFK/UMass Red Line Station will be exposed under a 10 percent annual chance flood event with 21 inches of SLR.

PROVIDE GUIDANCE ON PRIORITY EVACUATION AND SERVICE ROAD INFRASTRUCTURE TO THE ICC

The Office of Emergency Management should work with Boston Transportation Department, Department of Public Works, and private utilities to provide guidance on critical roads to prioritize for adaptation planning, including evacuation routes and roads required to restore or maintain critical services. Under 9 inches of SLR, four evacuation routes are exposed under a 1 percent annual chance flood event. These evacuation routes include I-93 South, Morrissey Boulevard, Neponset Avenue, and Gallivan Boulevard.

CONDUCT FEASIBILITY STUDIES FOR COMMUNITY ENERGY SOLUTIONS

The 2016 Boston Community Energy Study identified five sites in Dorchester as feasible locations for emergency microgrids due to their concentration of critical facilities. These sites are the intersection of Gallivan Boulevard and Neponset Avenue, Fields Corner, Codman Square, Four Corners/Geneva, and along Blue Hill Avenue. The Environment Department should work with local stakeholders and utility providers to explore this location. The proposed Gallivan Boulevard and Fields Corner sites are exposed to extensive stormwater flooding in the near term. The Gallivan Boulevard site also may be exposed to the 1 percent annual chance event as soon as the 2050s.

ADAPTED BUILDINGS

PROMOTE CLIMATE READINESS FOR PROJECTS IN THE DEVELOPMENT PIPELINE

Upon amending the zoning code to support climate readiness (see Initiative 9-2, p.135), the Boston Planning and Development Agency (BPDA) should immediately notify all developers with projects in the development pipeline in the future floodplain that they may alter their plans in a manner consistent with the zoning amendments (e.g., elevating their first-floor ceilings without violating building height limits), without needing to restart the BPDA permitting process. Currently, 39 residential and 18 commercial buildings are under construction or permitted in Dorchester, representing 3,067 additional housing units and six million square feet of new commercial space.

PREPARE MUNICIPAL FACILITIES FOR CLIMATE CHANGE

The Office of Budget Management should work with City departments to prioritize upgrades to municipal facilities in Dorchester that demonstrate high levels of vulnerability (in terms of the timing and extent of exposure), consequences of partial or full failure, and criticality (with highest priority for impacts on life and safety) from coastal flooding. Exposure to municipal facilities located in Dorchester is minimal in the near term. Later in the century, the McCormack Middle School, Paul A. Dever School, Boston Collegiate Middle School, and Engine 20 Fire Station will be exposed to flood impacts during the 1 percent annual chance event. To address extreme heat risks, the City should prioritize backup power installation at municipal facilities that demonstrate high levels of criticality, including specific Boston Centers for Youth and Family and Boston Public School facilities that serve as emergency shelters.

ESTABLISH A CLIMATE READY BUILDINGS EDUCATION PROGRAM FOR PROPERTY OWNERS, SUPPORTED BY A RESILIENCE AUDIT PROGRAM

The City should develop and run a Climate Ready Buildings Education Program and a resilience audit program to inform property owners about their current and future climate risk and actions they can undertake to address these risks. To prepare for the most immediate risks, the City should prioritize audits for buildings with at least a 1 percent annual chance of exposure to coastal and riverine flooding in the near term, under 9 inches of sea level rise. In Dorchester, this includes almost 170 structures, 35 percent of which are exclusively residential and 24 percent of which are industrial. A resilience audit should help property owners identify cost-effective, building-specific improvements to reduce flood risk, such as backflow preventers, elevation of critical equipment, and deployable flood barriers; promote interventions that address stormwater runoff or the urban heat island effect, such as green roofs or "cool roofs" that reflect heat; and encourage owners to develop operational preparedness plans and secure appropriate insurance coverage. The resilience audit program should include a combination of mandatory and voluntary, market-based and subsidized elements.

INCORPORATE FUTURE CLIMATE CONDITIONS INTO AREA PLANS AND ZONING AMENDMENTS

The City should incorporate future climate considerations (long-term projections for extreme heat, stormwater flooding, and coastal and riverine flooding) into major planning efforts in Dorchester. The City is conducting a planning process for Glover's Corner and plans to update the Joseph Moakley Park master plan. The Department of Conservation and Recreation is planning redesign and reconstruction of Morrissey Boulevard.

Downtown

The Downtown focus area comprises several neighborhoods that lie in the northern part of Boston, including the West End, the North End, the Financial District, Chinatown, and the Leather District.

The West End lies across the Charles River from Cambridge, between the Longfellow Bridge and the Charlestown Bridge. The North End sits at the northernmost corner of the Boston mainland, surrounded on two sides by the Boston Harbor, across from East Boston. Prior to the 2000s, the North End was cut off from the rest of the mainland by the elevated Central Artery (I-93), placed underground during the "Big Dig." The Financial District lies between the West End and North End and covers the largest extent of the focus area. Chinatown sits on the southern edge of Downtown, and the Leather District occupies nine blocks east of Chinatown.

Over the last three centuries, the Downtown focus area has been dramatically expanded through fill, as more land was needed to support population and industrial growth. The Downtown focus area was heavily impacted by urban renewal in the 1950s to 1970s, as evidenced by the construction of the Central Artery and clearing of sections of the West End.

Today, the Downtown focus area hosts a broad range of uses, reflecting the diverse neighborhoods that sit within it. The West End is currently in the process of a development boom that is revitalizing the residential and commercial components of the neighborhood. The neighborhood will look very different over the next ten years. In addition, this area has a strong institutional presence due to Massachusetts General Hospital and affiliated facilities. The North End is a vibrant mixed-use neighborhood, with historic brick apartments intermingled with infill, and main commercial corridors along Hanover and Salem Streets. The Financial District is a commercial center, with a number of high-rise buildings; a retail and recreational hub, with shopping at Downtown Crossing and the Theater District; and Government Center. Chinatown is a densely populated mixed-use district, with Tufts Medical Center located at its southern edge. The Leather District contains residential and commercial tenants attracted to historic brick warehouses that offer "loft" space.

Reflecting its status as a center of commerce, government, and recreation, Downtown is home to extensive transportation infrastructure, a significant part of which is underground. This infrastructure is critical for residents of the entire region to access jobs and essential services. It is anchored by South Station and adjacent to Fort Point Channel and North Station.

Downtown is highly exposed to sea level rise (SLR) impacts due to its extensive low-lying coastline, with multiple paths for inundation, and its exposure to flooding from the Charles River, Boston Harbor, and Fort Point Channel. Downtown is challenging for flood protection because activities on the waterfront are highly related to, and economically dependent on, direct visual and physical access to the waterfront.

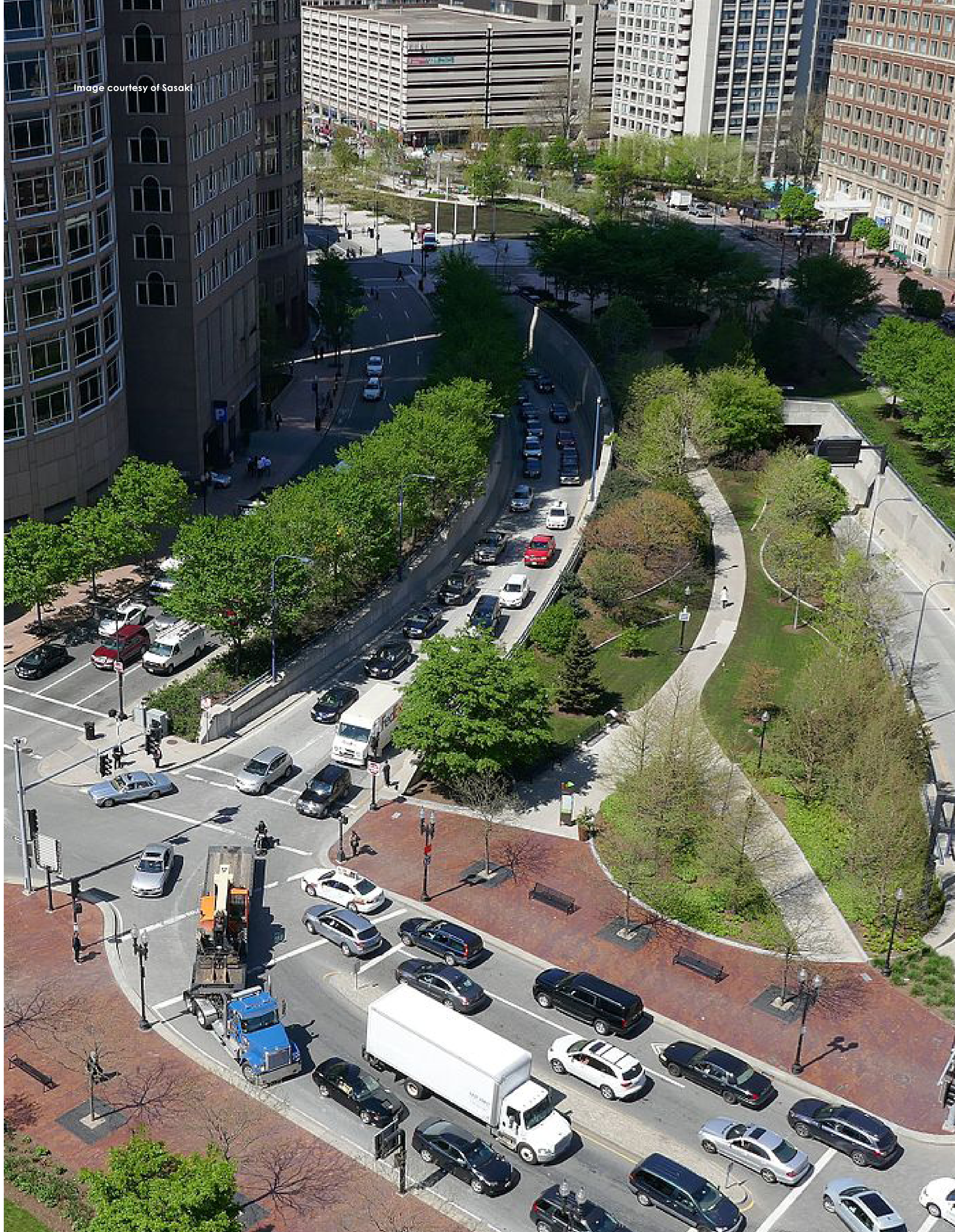


Image courtesy of Sasaki

FLOOD PROGRESSION

DEFINITIONS

Near term: Beginning 2030s, assumes 9 inches of sea level rise

Midterm: Beginning 2050s, assumes 21 inches of sea level rise

Long term: Beginning 2070s or later, assumes 36 inches of sea level rise

Exposure: Can refer to people, buildings, infrastructure, and other resources within areas likely to experience hazard impacts. Does not consider conditions that may prevent or limit impacts.

Vulnerability: Refers to how and why people or assets can be affected by a hazard. Requires site-specific information.

Consequence: Illustrates to what extent people or assets can be expected to be affected by a hazard, as a result of vulnerability and exposure. Consequences can often be communicated in terms of economic losses.

Annualized losses: The sum of the probability-weighted losses for all four flood frequencies analyzed for each sea level rise scenario. Probability-weighted losses are the losses for a single event times the probability of that event occurring in a given year.

*For a full list of definitions, refer to the Glossary in the Appendix.

Downtown is exposed to climate change impacts including heat, increased precipitation and stormwater flooding, sea level rise, and coastal and riverine flooding. Exposure to heat and stormwater flooding are addressed in the Citywide Vulnerability Assessment, while exposure and consequences to coastal and riverine flood risk are further discussed in this section.

In the near term, low-lying waterfront areas between the Sumner Tunnel, which carries traffic across Boston Harbor from Route 1A in East Boston; the Financial District; and areas near the Charles River Dam are most at risk. The lowest-lying areas are near the New England Aquarium and are exposed to high-probability storm events (10 percent annual chance) in the near term.

9 INCHES SEA LEVEL RISE

21 INCHES SEA LEVEL RISE

36 INCHES SEA LEVEL RISE

LEGEND

- Highest Monthly High Tide
- 10% Storm Flooding
- 1% Storm Flooding
- Roads
- Major Roads
- Major Tunnels
- Evacuation Route
- Evacuation Route Tunnels
- MBTA Blue Line
- Parks
- MBTA Silver Line Station
- MBTA Station
- College or University
- Tunnel Entrance
- School
- Police Station
- Fire Station
- Hospital
- Health Care Facility

Other Essential Facilities and Shelters

1. Nazzaro Community Center
2. Ambulance 1
3. Station 8

- BHA Public Housing
- Senior Housing
- Longterm Care Facility
- Prison
- DCR Spray Deck or Pool

Much of the Downtown waterfront will be exposed to coastal flooding by the end of the century. High tides are expected to impact inland areas near Faneuil Hall and the New England Aquarium. In addition, other parts of the waterfront that are out of the 1 percent annual chance floodplain earlier in the century are expected to be at risk by the end of the century.

Though Downtown's total land area at risk from coastal and riverine flooding is small compared to some focus areas, the land areas that are exposed are densely developed, likely leading to significant impacts in terms of structural damage and economic losses.

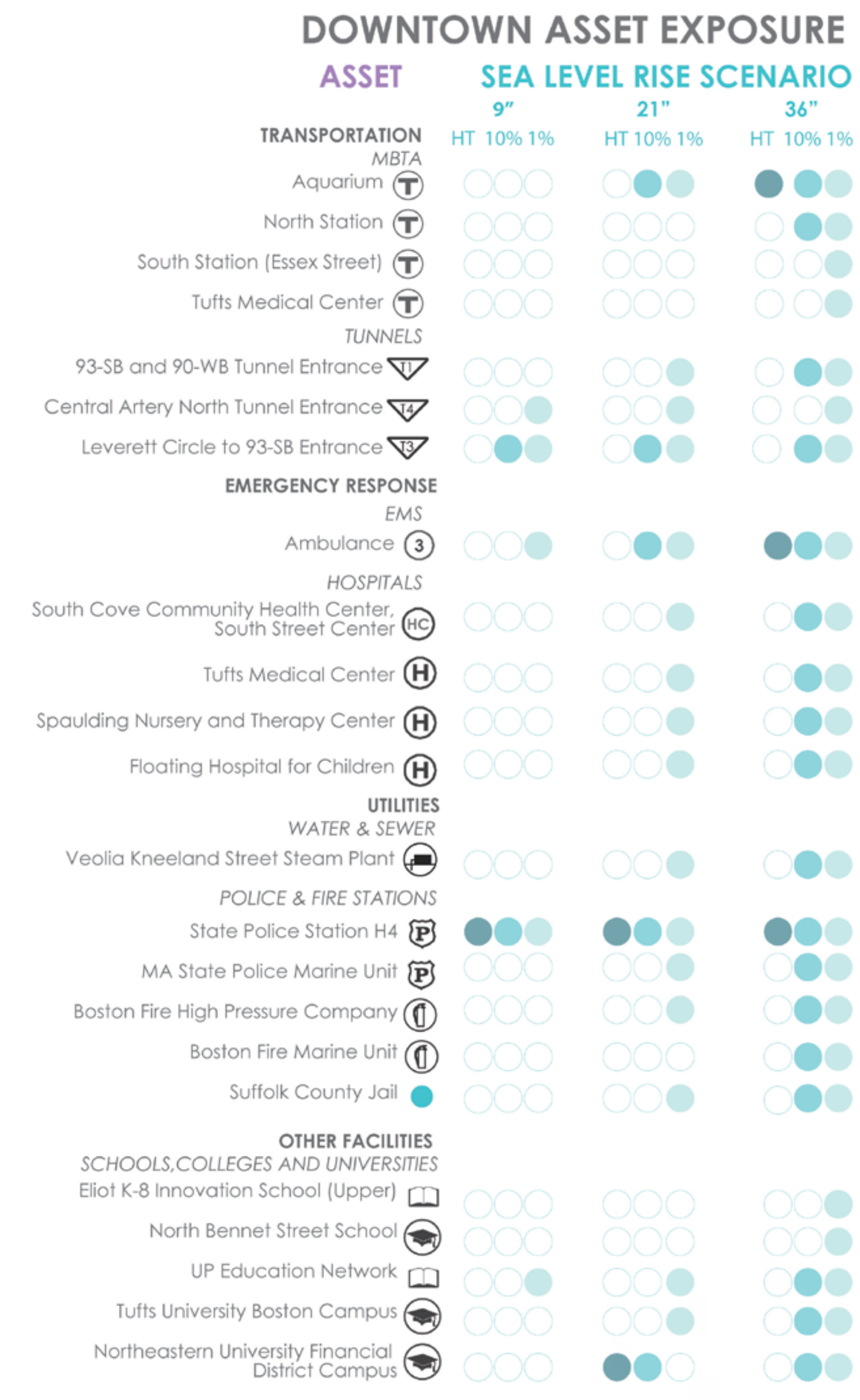
The topography of the Downtown focus area is shaped both by natural landforms and areas that were filled in the early and mid-1800s. The North End, for example, is largely naturally occurring high ground. On the other hand, the Mill Pond area, at the northern edge of the West End, was filled in the early 1800s, while the fill areas east and south of the North End were separately filled in the early to mid-1800s. These fill areas generally make up the lowest lying and most vulnerable areas to coastal and riverine flooding within Downtown.

In the near term, low-lying waterfront areas near the Charles River Dam and the New England Aquarium are the source of the most significant flood risk Downtown. The land near the aquarium is the lowest-lying in all of Downtown, leading to the greatest exposure to high-probability coastal floods in the near term. Expected exposure to the 10 percent annual chance storm events in the near term extends as far inland as Faneuil Hall.

In the second half of the century, large areas near the aquarium and Faneuil Hall are expected to be exposed to flooding under high-probability storm events. In addition, the floodplain is expected to expand toward the West End and along the waterfront edge between the Sumner Tunnel and Charles River Dam.

Areas exposed to flooding only under low-probability events (1 percent annual chance or greater) in the near term are expected to be exposed to flooding during monthly high tides later in the century. This includes the aquarium and Faneuil Hall. Furthermore, most waterfront edges will be exposed to high-probability storm events (10 percent annual chance) by the end of the century, exposing densely developed areas during relatively frequently occurring storms.

Waterfront areas near the Charles River Dam and the New England Aquarium require resilience planning in the near term. Sections of the North End and Financial District require planning to mitigate loss before the end of the century.

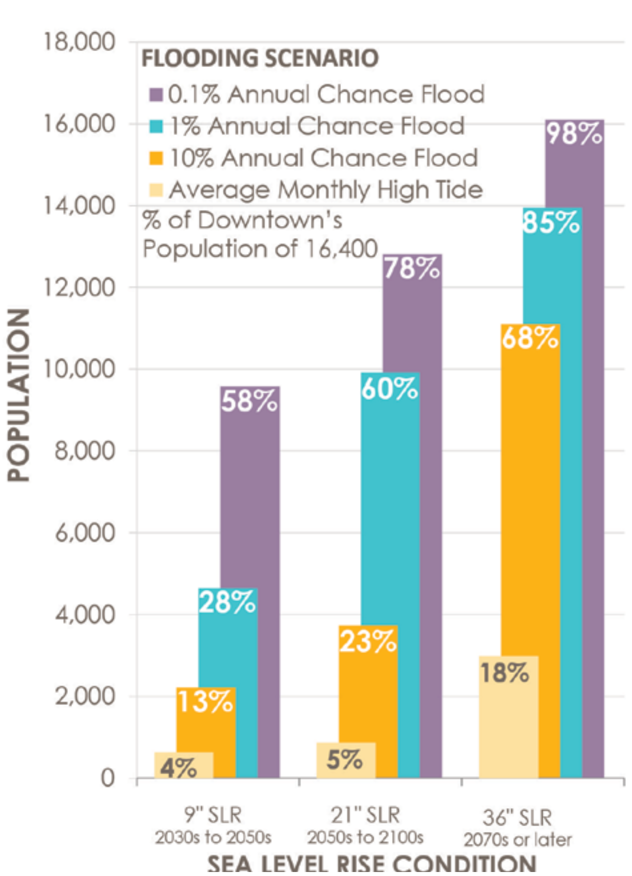


EXPOSURE
POPULATION & INFRASTRUCTURE

POPULATION AND SOCIAL VULNERABILITY

Residents of Downtown comprise about 5 percent of Boston's overall population, or about 30,000 people. Compared to the citywide average, Downtown has a smaller share of children, adults with low to no income, people with disability, and people of color, although one-third of the Downtown population still consists of people of color. The population has a larger share of older adults and a significantly larger share of renters and people without vehicles, as is typical of a downtown area. For this reason, the population residing within this area could be disproportionately affected by any disruptions

DOWNTOWN POPULATION EXPOSURE



in public transportation service, as well as loss of electricity and other utilities, particularly during summer or winter months, when climate regulation indoors is necessary for resident well-being.

In the near term, 630 people are expected to be exposed to flooding during monthly high tide, the highest of any focus area. In addition, approximately 2,190 people live in areas expected to be flooded by a high-probability flood event (10 percent annual chance), and 4,680 people live in areas expected to be flooded by a low-probability flood event (1 percent annual chance), making Downtown the second-most-exposed focus area (in terms of people) after East Boston for these events in the near term. The Austonia Public Housing development, with approximately 100 units for the elderly, is expected to be exposed to near-term, low-probability flood events (1 percent annual chance event) and more frequent storms throughout the century.

Throughout the mid- to late century, for both high- and low-probability events, Downtown can consistently expect to have the second- or third-highest population affected by flooding of any Boston focus area, behind East Boston and South End, depending upon the coastal storm condition and sea level rise scenario. Later in the century, Downtown shelter needs are expected to be around 1,000 individuals under the low-probability flood event (1 percent annual chance event). Since there are no emergency shelters located Downtown, those needing shelter will have to travel to other neighborhoods. This is especially critical for Downtown's concentrations of older people and those without vehicles. The Charles River neighborhoods, the South End, East Boston, and South Boston may have viable sheltering options for Downtown residents, though these neighborhoods are all expected to require more shelter space for their populations, and there may be access challenges associated with reaching them.[1]

INFRASTRUCTURE

Various transportation connections from Downtown to Charlestown, East Boston, and South Boston across waterways may be exposed to flood impacts at some time this century.

Tunnels and bridges that lead out of Downtown may be exposed to near-term sea level rise and coastal storms, particularly the I-93 North corridor that connects Downtown and Charlestown. Other evacuation route tunnels and bridges expected to be exposed in the near term include the North Washington Bridge entrance next to Lovejoy Wharf that connects the North End and Charlestown, I-90/Ted Williams Tunnel entrances near Fort Point Channel (Seaport District exposure in the near term may impact bridge travel), and Sumner/Callahan Tunnel entrances in the northern end of Downtown. Two stormwater pumps that protect the I-90 portals are also exposed to mid-century flooding from low-probability storm events (1 percent annual chance), although site-specific evaluations should be conducted to assess true vulnerability and consequences of impact.

Two of the three MBTA stations that support connectivity from Downtown to East Boston and

[1] Vehicle ownership is not a factor considered in shelter-need calculations and, as such, the estimate may be conservatively low. A resident without a personal vehicle may find it more difficult to evacuate and find access to a shelter than a resident with a personal vehicle.


Image courtesy of Sasaki

Charlestown may be exposed to flooding from sea level rise and coastal storms within this century. In particular, the Blue Line's Aquarium Station may be exposed to high-probability flood events (10 percent annual chance) in the near term. If the Downtown Aquarium Station and East Boston's exposed MBTA stations lose service due to flood impacts, Blue Line service could be interrupted from Downtown through Revere. This situation could lead to approximately 18,500 riders in need of alternative transportation options, leading to strains on other public transportation systems and affecting traffic patterns on a large scale. In addition, late-century storms and sea level rise may also impact Orange Line service between Charlestown and Downtown. The two stations (Community College and North Station) that connect these neighborhoods are exposed to the low-probability flood event (1 percent annual chance). North Station is a major hub for Amtrak and MTBA, and exposure to low-probability flood events and sea level rise in the late century may cause large scale impacts to transportation systems in Downtown, Charlestown, and East Boston.

MBTA's Red Line also services the Downtown area and connects Cambridge to South Boston. Portions of the Red Line that run through Downtown remain largely unexposed to flood impacts until later in the century; sections of the line proximate to the Charles River and the Charles/MGH Stations are exposed to the 1 percent chance event.

Planned expansion of MBTA's South Station must consider effects of sea level rise and coastal storm flooding while choosing the location of a train yard.

The South Station Intermodal Transportation Center is expected to be exposed to low-probability coastal and riverine flooding later in the century. Redevelopment of the station and location of a new train yard must consider sea level rise and coastal flood impacts to ensure that investments are protected in the long term. One-third of Downtown's emergency response services may be exposed to late-century flood impacts.

In the near term, State Police Station H-4, which has within its jurisdiction the Museum of Science, the Esplanade and Hatch Shell, and some of Boston's major hospitals,[2] is expected to be exposed to monthly high tides. While site-specific review is required to assess vulnerabilities to sea level rise, access interruption can be expected at the least. In addition, one of the three EMS stations located Downtown may experience exposure to low-probability (1 percent annual chance) storm events in the near term.

In the second half of the century, one of two Boston Fire Department facilities located Downtown may be exposed to low-probability storm events. Both facilities are exposed to high-probability storm events later in the century (10 percent annual chance). Exposure of emergency services such as fire, police, and medical may hinder Downtown's internal emergency-response capacity.

In addition, in the second half of the century, the Suffolk County Jail could be exposed to low-probability storm events. The facility has 650 beds. Evacuation and relocation of inmates in the case of a forecasted coastal storm could result in overcrowding at other facilities. Site-specific evaluation of this facility is necessary to understand vulnerabilities and consequences of impacts.

Heating and cooling of Downtown office buildings may be compromised by low-probability mid-century storms and sea level rise. Low-probability late-century storms are expected to render Boston's steam system inoperable.[3]

The Veolia Kneeland Street steam plant provides Downtown office buildings with heat and hot water in the winter and air conditioning and cold water in warmer months. If substantial flooding is experienced at the facility in the near term, it may be rendered inoperable. Steam will then have to be exported from the Kendall Station in Cambridge and the Scotia plant in Fenway/Kenmore, reducing Boston's steam capacity by at least 50 percent. Though the distribution system is expected to return to normal operation shortly after flood levels recede, customers within the flood extent will likely experience temporary curtailments or isolations in their steam supply, in addition to select customers south of Kneeland Street, Northwest Boston, Quincy Market area, and Long Wharf area. Late-century flooding at Kneeland, Kendall, and Scotia Stations are expected to result in system failure, which will not be normalized until steam supply points can be repaired.

Loss of heating and cooling services in Downtown commercial buildings could potentially affect work productivity. Employees that work in facilities without heat capabilities may choose to stay home on extremely cold days. Alternatively, air conditioning is often necessary to keep computer systems, data centers, and other electrical equipment cool. Loss of air conditioning may cause such assets to overheat and shut down, resulting in lost work productivity. Loss of heating and cooling capacity across the city could have detrimental impacts to residents, particularly if storm events coincide with heat waves or cold weather.

Tufts Medical Center campus, including the Floating Hospital, Dental Center, and Rehabilitation Center, could be exposed to low-probability mid-century coastal storms.

Portions of the Tufts campus may be exposed to the low-probability (1 percent annual chance) storm event in the second half of the century.[4] The frequency of Tuft's exposure to coastal storms can be expected to increase with sea level rise and could potentially affect the facility's emergency center. Any full or partial service interruption at Tufts will likely have an effect on Massachusetts General Hospital, also located Downtown. Though Massachusetts General Hospital is not likely to be exposed to flood impacts during this century, potential overcrowding at the facility can lead to swift resource depletion and a delay in necessary emergency care post-event.

[4]Source: "Station H-4, SP Boston." The Massachusetts Executive Office of Public Safety and Security. http://www.mass.gov/eopss/law-enforce-and-cj/law-enforce/msp-troops/troop-h/station-h-4-sp-boston.html.

[3]Flood impacts are based on existing conditions of Veolia facilities. Near-term flood impacts may be managed through the potential upcoming replacement of Kneeland Station.

[4]Site-specific review of Tufts Medical Center assets is necessary.

EXPOSURE AND CONSEQUENCES
BUILDINGS AND ECONOMY

RISK TO BUILDINGS

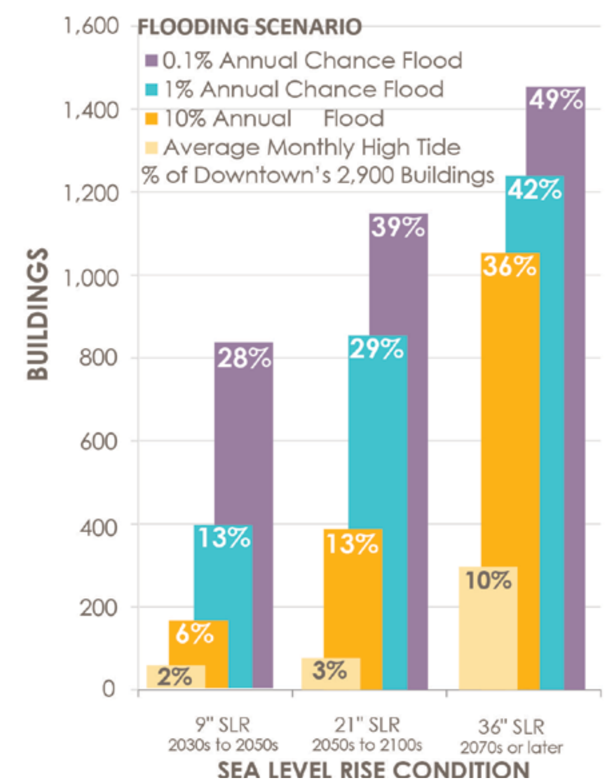
In the near term, Downtown is expected to have approximately 60 structures exposed to flooding during monthly high tides—the largest number of exposed structures, ahead of Charlestown and East Boston. Downtown has more than double the current real estate market value exposed to monthly high-tide flooding compared to any other focus area in Boston. However, Downtown's near-term high-tide exposure is concentrated in a relatively small area—17 acres, compared to 90 acres in Dorchester. Mixed-use and residential uses together account for approximately 70 percent of the real estate market value exposed.

Additionally, low-probability coastal flood events in the near term lead to an exposed market value in Downtown that is roughly half of that for South Boston for the same event. Downtown has 390 structures exposed to flooding during a low-probability flood event (1 percent annual chance), behind only East Boston and South Boston.

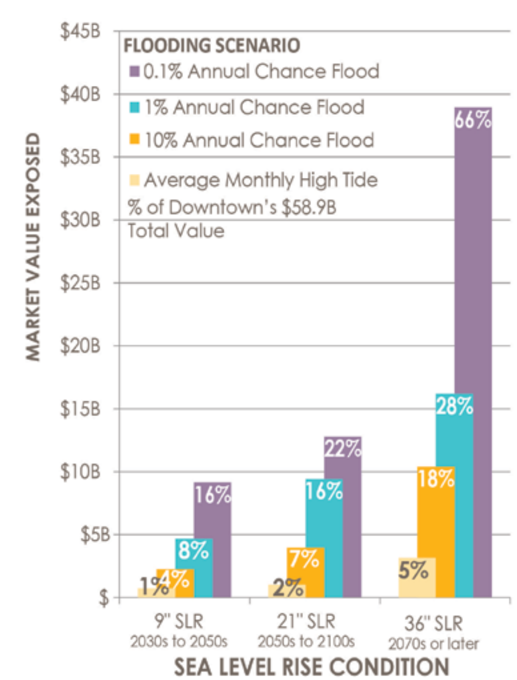
Expected annualized losses for Downtown make up about one-third of all those expected citywide in the near term and over 20 percent of all expected citywide losses toward the end of the century.

In the late century, Downtown is expected to have 300 structures exposed during monthly high tides, five times as many as in the near term, and 1,240 structures exposed to flooding during a low-probability flood event (1 percent annual chance), more than 35 times as many as in the near term. Roughly 25 percent of the structures exposed to the 1 percent annual chance event are commercial, roughly 35 percent are mixed-use, and roughly 30 percent are residential. Land acreage exposed in Downtown is relatively low when compared to other high-exposure neighborhoods under all flood scenarios. For example, the Downtown land area exposed to high-tide flooding late in the century is roughly 20 percent of acres exposed in South Boston and only 15 percent the exposed area in East Boston. This speaks to the high concentration of structures in Downtown Boston. A detailed evaluation would need to be conducted to determine whether waterfront shoreline protections or building-level adaptations would have a greater effect on reducing loss in this area over the near and long term.

DOWNTOWN BUILDING EXPOSURE



DOWNTOWN MARKET VALUE EXPOSURE



RISK TO THE ECONOMY

As of 2014, there are over 12,200 jobs in Charlestown, and associated industries contribute over $2.5 billion of output (sales and revenues) into the city's economy annually. The Charlestown economy is well balanced, as no single industry comprises more than an 8 percent share of employment or output within the neighborhood.

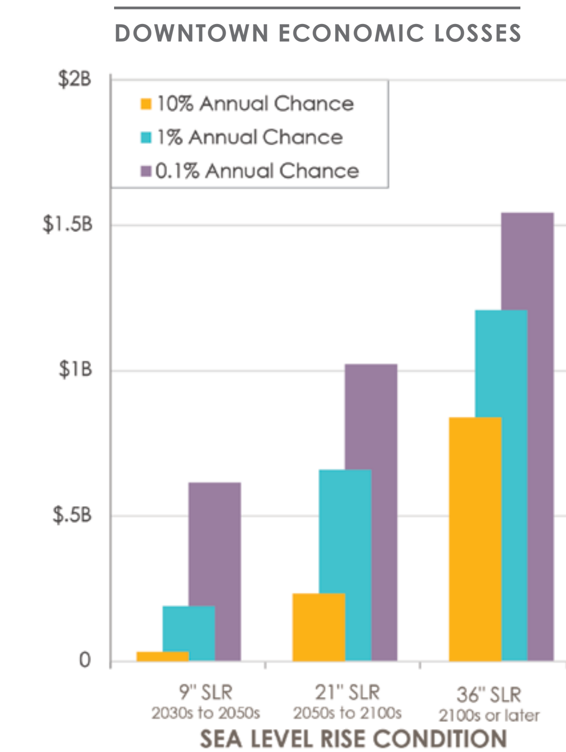
Charlestown's economy is most vulnerable in medium- and long-term climate scenarios. Based on the neighborhood's current economy and building stock conditions, $8 million in annualized output loss and approximately 50 positions in annualized employment loss are expected toward the end of the century. Scientific research and development, accounting, and insurance-related services rank among top industries expected to be impacted. Losses have been calculated strictly based on expected flooding to structures, as opposed to egress and utility lines, and cascading loss of function impacts are not considered in the analysis.[6] In the second half of the century, the site of a current martial arts training center is expected to be heavily impacted by floodwaters and joins top industries expected to be affected by coastal storm events.

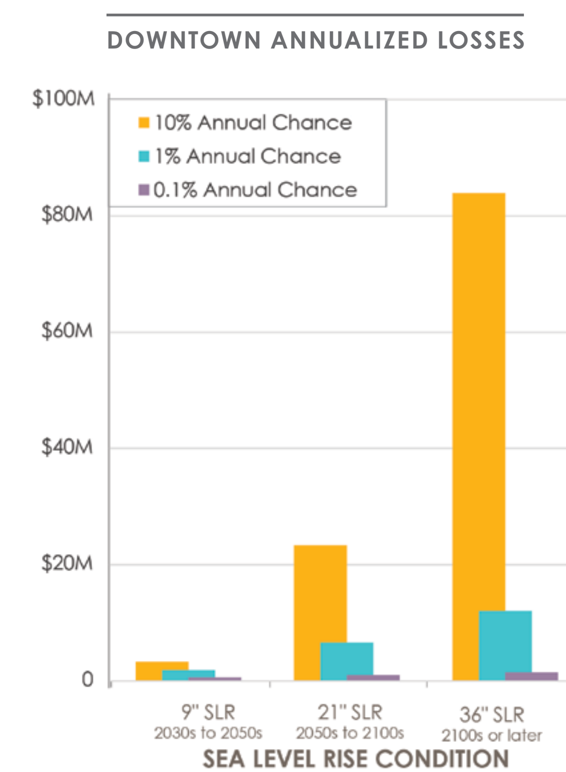
[6]More-detailed analysis would be required to quantify expected loss of function impacts to utilities and transportation outside of economic loss derived from direct physical damage to structures.

ECONOMIC RISK ASSUMPTIONS

Job and output loss include direct, indirect, and induced consequences of flood impacts. Direct results are impacts felt within a neighborhood, while indirect and induced results are those expected to be felt throughout Suffolk County as a result of changes in spending patterns. Results for both job and output losses are the sum of annualized values for the four flood frequencies analyzed for each sea level rise scenario. This represents a lower-bound estimate for several reasons. First, not all probabilistic events are considered. Second, the analysis assumes that all impacted businesses eventually reopen, though FEMA estimates that almost 40 percent of small businesses—and up to 25 percent of all businesses—never reopen after experiencing flood impacts. Third, only building areas directly impacted by floodwater are assumed to experience business interruption. This does not consider interruptions of businesses due to loss of power or utility functions. Finally, the analysis only considers existing populations, businesses, and buildings and does not include projections for future growth. Refer to the Appendix for a more detailed explanation of the exposure and consequence analysis.

INDUSTRY	ANNUALIZED LOSS OF ECONOMIC OUTPUT
Restaurants	$15,400,000
Hospitals and Other Medical Services	$8,600,000
Retail	$4,200,000
Real Estate	$5,200,000
All Other Industries	$34,900,000
Total	**$68,300,000**





Over $700 million in current real estate market value is exposed to high-tide flooding in the near term, the highest amount of any neighborhood.

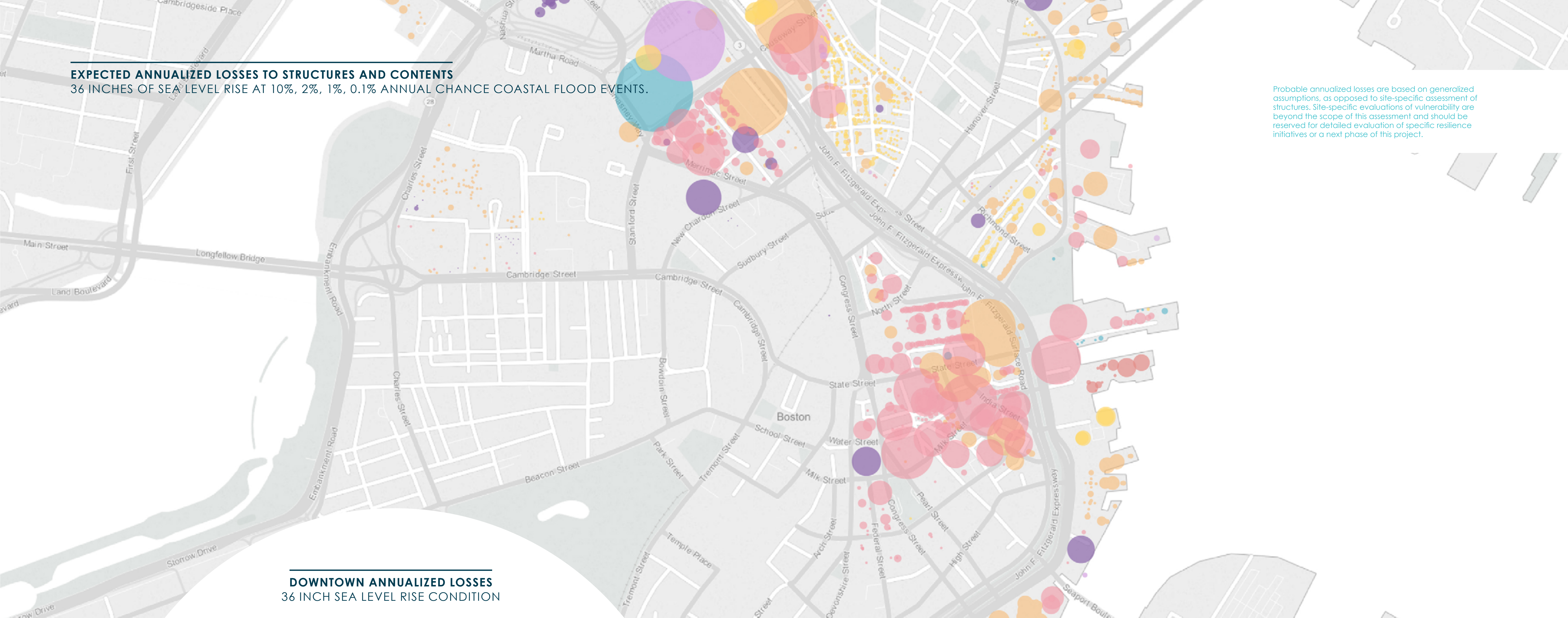
Projected losses Downtown are concentrated in a smaller area than other neighborhoods expected to experience comparable direct damage impacts through the century.

Restaurant and retail industries will be particularly hard hit by flood impacts due to inherent impediments to temporary relocation for such businesses, as well as their roles in supporting the area. As these industries are known to support low- to moderate-income employees, special planning considerations will be needed to mitigate loss to vulnerable populations.

EXPECTED ANNUALIZED LOSSES TO STRUCTURES AND CONTENTS

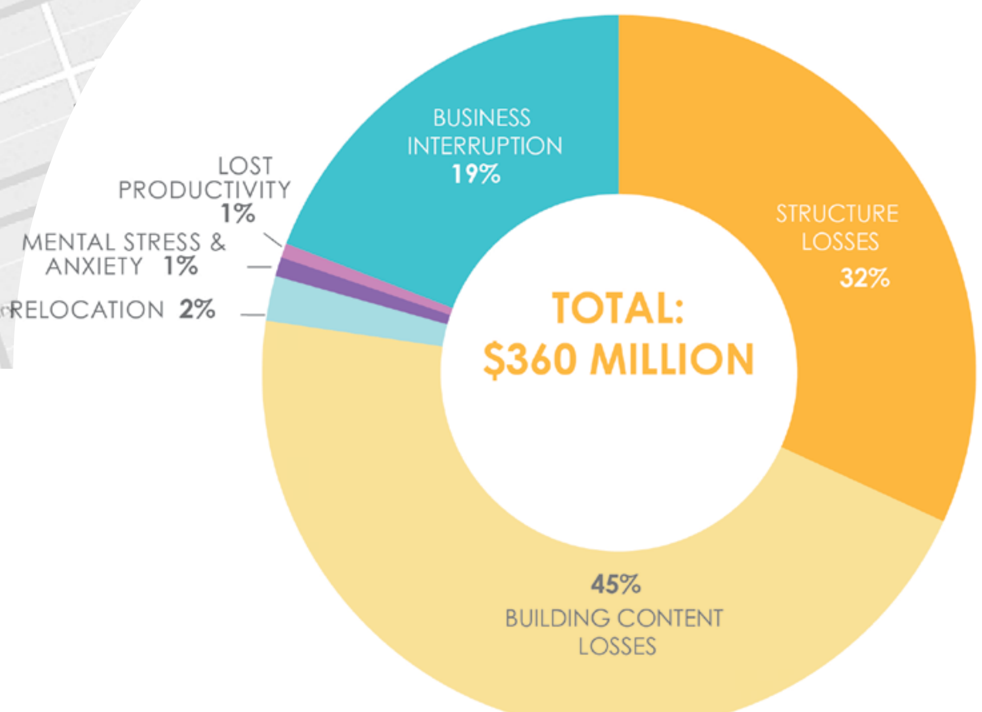
36 INCHES OF SEA LEVEL RISE AT 10%, 2%, 1%, 0.1% ANNUAL CHANCE COASTAL FLOOD EVENTS.

Probable annualized losses are based on generalized assumptions, as opposed to site-specific assessment of structures. Site-specific evaluations of vulnerability are beyond the scope of this assessment and should be reserved for detailed evaluation of specific resilience initiatives or a next phase of this project.



DOWNTOWN ANNUALIZED LOSSES

36 INCH SEA LEVEL RISE CONDITION



- Commercial ($99.2M)
- Cultural/Religious, Edu, Rec ($49.3M
- Essential Services ($22.2.0M)
- General Government ($10.1M)
- Industrial/Transportation($2.4M)
- Mixed Use ($92.4M)
- Residential ($13.1M)

Total ($289M)

≥$10.0M | $8.0M | $6.0M | $4.0M | $2.0M

Each circle represents annualized losses suffered by an individual building. Larger circle size indicates higher contents and structures losses. Annualized losses take into consideration the annual probability of an event occurring, as well as the projected impacts of such an event.

DOWNTOWN
APPLICATION OF RESILIENCE INITIATIVES

PROTECTED SHORES

DEVELOP LOCAL CLIMATE RESILIENCE PLANS TO SUPPORT DISTRICT-SCALE CLIMATE ADAPTATION

The City should develop a local climate resilience plan for Downtown to support district-scale climate adaptation. The plan should include the following:

- **Community engagement** through a local climate resilience committee, leveraging existing local organizations and efforts.
- **Land-use planning for future flood protection systems,** including Flood Protection Overlay Districts in strategically important "flood breach points" identified below (see Potential Flood Protection Locations).
- **Flood protection feasibility studies,** evaluating district-scale flood protection, including at locations identified below (see Potential Flood Protection Locations).
- **Infrastructure adaptation planning** through the Infrastructure Coordination Committee. For Downtown, the Massachusetts Department of Conservation and Recreation is a key partner, as it controls the New Charles River Dam.
- **Coordination with other plans**, including Imagine Boston 2030, GoBoston 2030, Special Planning Areas, the Downtown Waterfront Municipal Harbor Plan, and any future Municipal Harbor Plan processes.
- **Development of financing strategies and governance structures** to support district-scale adaptation.

ESTABLISH FLOOD PROTECTION OVERLAY DISTRICTS AND REQUIRE POTENTIAL INTEGRATION WITH FLOOD PROTECTION

The Boston Planning and Development Agency (BPDA) should petition the Boston Zoning Commission to create new Flood Protection Overlay Districts in areas that are strategically important for potential future flood protection infrastructure (see Potential Flood Protection Locations below). Within a Flood Protection Overlay District, a developer would be required to submit a study of how a proposed project could be integrated into a future flood protection system; options may include raising and reinforcing the development site or providing room for a future easement across the site.

PRIORITIZE AND STUDY THE FEASIBILITY OF DISTRICT-SCALE FLOOD PROTECTION

To reduce the risk of coastal flooding at major inundation points, the City should study the feasibility of constructing district-scale flood protection at the primary flood entry points Downtown (see Potential Flood Protection Locations below for a preliminary identification of locations and potential benefits).

These feasibility studies should take place in the context of local climate resilience plans, featuring engagement with local community stakeholders, coordination with infrastructure adaptation, and considerations of how flood protection would impact or be impacted by neighborhood character and growth. Examples of prioritization criteria include the timing of flood risk, consequences for people and the economy, social equity, financial feasibility, and potential for additional benefits beyond flood risk reduction.

SLR SCENARIO	DISTRICT SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD[7]
9" SLR (2030s–2050s)	Downtown Waterfront and the New Charles River Dam
21" SLR (2050s–2100s)	Downtown Waterfront and the New Charles River Dam
36" SLR (2070s or later)	Downtown Waterfront, the New Charles River Dam, South Boston Waterfront, and Dorchester Bay locations combined

POTENTIAL DISTRICT-SCALE FLOOD PROTECTION LOCATIONS[6]

See District-Scale Flood Protection Systems Overview section (page Y) for a citywide perspective on district-scale flood protection. District-scale flood protection is only one piece of a multilayered solution that includes prepared and connected communities, resilient infrastructure, and adapted buildings.

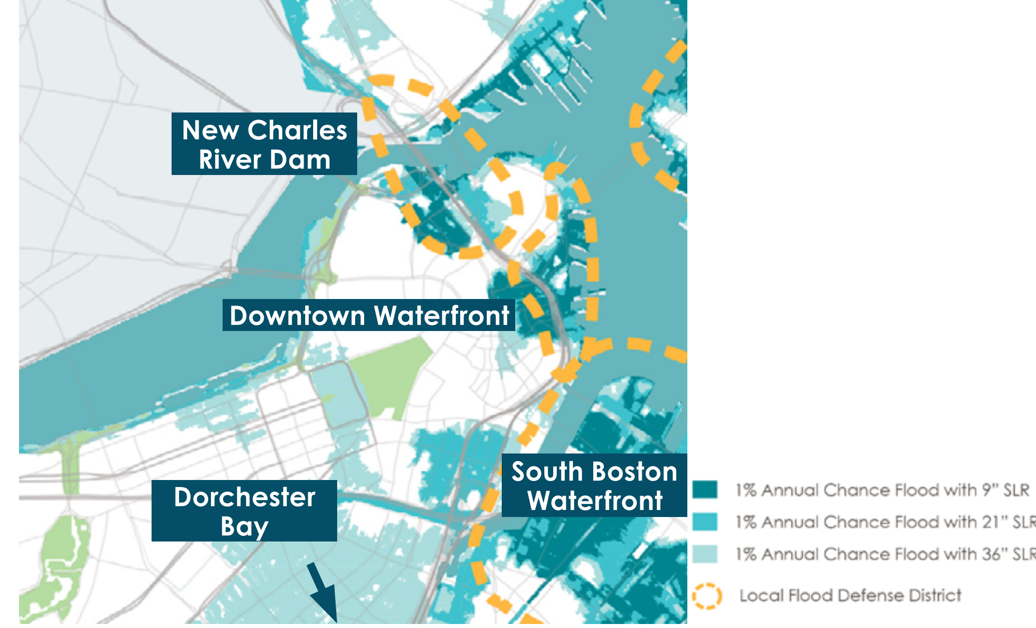
In the near term, flood protection at two locations is critical:

- **The Downtown Waterfront**, addressing flood entry points along the low-lying eastern edge of Downtown; and
- **The New Charles River Dam,** addressing potential overtopping or flanking of the dam, which would inundate areas around North Station and the West End.

While flood protection at the waterfront would stay independently effective through the end of the century, protection at the dam would eventually need to be combined with interventions addressing flood risk from South Boston and Dorchester Bay in order to provide flood risk reduction to Boston's interior neighborhoods.

LOCATIONS

- **The Downtown Waterfront Location** is focused on flood entry points along the low-lying eastern edge of Downtown, starting in the North End and extending to the mouth of Fort Point Channel. Flood protection solutions could include a series of barriers, potentially encompassing floodwalls, greenways, or berms. Potential alignments include along the path of the Rose Kennedy Greenway, connecting high ground near Hanover Street in the north with high ground near Oliver Street in the south, or closer to the waterfront, with potential integration with Christopher Columbus Park.
- **The New Charles River Dam Location,** also described in the Charlestown focus area, is focused on flood pathways by the Zakim Bridge / New Charles River Dam, which would inundate the northern section of Downtown. Potential flood protection solutions could include a tide barrier across the mouth of Miller's River, a tide gate and connecting flood protection system just west of Littoral Way, or a deployable barrier across the railroad right-of-way connecting Charlestown and North Station.
- **The South Boston Waterfront Location,** described in the South Boston focus area, is focused on flooding from Fort Point Channel that would affect the southern areas of Downtown such as Chinatown and the Leather District.
- **The Dorchester Bay Location,** described in the Dorchester focus area, is focused on flooding from Dorchester Bay, which could reach parts of Downtown if not addressed.



DETAILED CONSIDERATIONS

- **Independent protection at the Downtown Waterfront location throughout the century:** The flood pathway around the Downtown Waterfront location is relatively isolated from other flood pathways, so no additional alignments are necessary to protect this area.
- **Large number of waterfront commercial buildings protected at the Downtown Waterfront location:** The majority of buildings protected by flood protection at this location are commercial buildings.
- **Many neighborhoods benefit from dam flood protection:** Flood protection at the New Charles River Dam could simultaneously protect parts of northern Downtown, southern Downtown, Charlestown, the Charles River neighborhoods, and the South End and Roxbury.
- **Requirement for multiple protection locations in the late century:** Though flood protection at the New Charles River Dam is expected to be able to protect northern sections of Downtown throughout the century, additional interventions at the South Boston Waterfront and Dorchester Bay are necessary to protect southern portions of Downtown, the South End, South Boston, and portions of Roxbury and Dorchester from flooding later in the century.

[6]These preliminary coastal flood protection concepts are based on a high-level analysis of existing topography, rights-of-way, and urban and environmental conditions. Important additional factors, including existing drainage systems, underground transportation and utility structures, soil conditions, and zoning, as well as any potential external impacts as a result of the project have not been studied in detail. As described in Initiatives 5-2 and 5-3, detailed feasibility studies, including appropriate public and stakeholder engagement, are required in order to better understand the costs and benefits of flood protection in each location.

[7]Additional flood protection may be required for flood events more severe than the 1 percent annual chance flood. See Appendix for more detailed information on expected effectiveness of flood protection systems, including analysis of additional flood protection locations and flood frequencies.

PREPARED & CONNECTED COMMUNITIES

CONDUCT AN OUTREACH CAMPAIGN TO PRIVATE FACILITIES THAT SERVE VULNERABLE POPULATIONS TO ENSURE THAT THEY ENGAGE IN EMERGENCY PREPAREDNESS AND ADAPTATION PLANNING

The City should conduct outreach to managers of facilities in Downtown that serve significant concentrations of vulnerable populations and are not required to have operational preparedness and evacuation plans under current regulations. Targeted facilities will include affordable housing complexes, substance abuse treatment and rehabilitation centers, daycare facilities, food pantries, small nonprofit offices, and others. The City should also conduct outreach to hotel and tourism attraction operators, given the role that they play in serving transient populations. An illustrative example of the type of facilities to which the City might conduct outreach is the Kinder Care Learning Center.[8] This facility is exposed to near-term damage from sea level rise and coastal flooding, in addition to access issues related to near-term stormwater flooding.

EXPAND BOSTON'S SMALL BUSINESS PREPAREDNESS PROGRAM

The City should reach out to small businesses in Downtown exposed to stormwater flooding in the near term or coastal flooding under a 1 percent annual chance event at 9 inches of SLR to help them develop business continuity plans, evaluate insurance coverage needs, and identify low-cost physical adaptations. Under a 1 percent annual chance event at 9 inches of SLR, 185 commercial buildings and 131 mixed-use buildings that could host small businesses are exposed to flood risk. Furthermore, the Chinatown Main Street District is expected to have isolated portions exposed to stormwater flooding in the near term and throughout the century. The Chinatown Main Street District also will be significantly exposed to coastal flood impacts by low-probability storms in the mid-century.

[8]The City did not review the extent of existing preparedness planning as part of this study.

RESILIENT INFRASTRUCTURE

ESTABLISH INFRASTRUCTURE COORDINATION COMMITTEE

The Infrastructure Coordination Committee (ICC) should support coordinated adaptation planning for Downtown's key infrastructure systems, including energy, transportation, water and sewer, and environmental assets. The City should support the MBTA in conducting a full asset-level vulnerability assessment of its system, including the Red Line. The MBTA is currently conducting a vulnerability assessment of the Blue Line. The Blue Line Aquarium Station will be exposed to flooding at 9 inches of SLR under a 1 percent annual chance event.

PROVIDE GUIDANCE ON PRIORITY EVACUATION AND SERVICE ROAD INFRASTRUCTURE TO THE ICC

The Office of Emergency Management should work with Boston Transportation Department, Department of Public Works, and private utilities to provide guidance on critical roads to prioritize for adaptation planning, including evacuation routes and roads required to restore or maintain critical services. With 9 inches of SLR, under a 1 percent annual chance flood event, Interstate 93, Atlantic Avenue, Summer Street, Congress Street, and Nashua Street are exposed to coastal flooding.

CONDUCT FEASIBILITY STUDIES FOR COMMUNITY ENERGY SOLUTIONS

The 2016 Boston Community Energy Study identified the North End as a potential location for an emergency microgrid, based on its concentration of critical facilities. The Environment Department should work with local stakeholders and utility providers to evaluate this site. The proposed location is expected to remain largely unexposed to both coastal and stormwater flooding throughout the century.

ADAPTED BUILDINGS

PROMOTE CLIMATE READINESS FOR PROJECTS IN THE DEVELOPMENT PIPELINE

Upon amending the Zoning Code to support climate readiness (see Initiative 9-2), the Boston Planning and Development Agency (BPDA) should immediately notify all developers with projects in the development pipeline in the future floodplain that they may alter their plans in a manner consistent with the zoning amendments (e.g., elevating their first-floor ceilings without violating building height limits), without needing to restart the BPDA permitting process. Currently, 39 residential and 18 commercial buildings are under construction or permitted Downtown, representing 3,067 additional housing units and six million square feet of new commercial space.

INCORPORATE FUTURE CLIMATE CONDITIONS INTO AREA PLANS AND ZONING AMENDMENTS

The Boston Planning and Development Agency should incorporate future climate considerations (long-term projections for extreme heat, stormwater flooding, and coastal and riverine flooding) into major planning efforts in Downtown. The City is currently drafting the Downtown Waterfront Municipal Harbor Plan. In addition, the State Department of Conservation and Recreation is evaluating options for Storrow Drive Tunnel repair or reconstruction.

ESTABLISH A CLIMATE READY BUILDINGS EDUCATION PROGRAM FOR PROPERTY OWNERS, SUPPORTED BY A RESILIENCE AUDIT PROGRAM

The City should develop and run a Climate Ready Buildings Education Program and a resilience audit program to inform property owners about their current and future climate risks and actions they can undertake to address these risks. To address the most immediate risks, the City should prioritize audits for buildings with at least a 1 percent annual chance of exposure to coastal and riverine flooding in the near term, under 9 inches of SLR. Downtown, this includes almost 400 structures, with 42 percent of these consisting of residential and mixed-use buildings that house residents. A resilience audit should help property owners identify cost-effective, building-specific improvements to reduce flood risk, such as installing backflow preventers, elevating critical equipment, and obtaining deployable flood barriers; promote interventions that address stormwater runoff or the urban heat island effect, such as green roofs or "cool roofs" that reflect heat; and encourage owners to develop operational preparedness plans and secure appropriate insurance coverage. The resilience audit program should include a combination of mandatory and voluntary, market-based, and subsidized elements.

PREPARE MUNICIPAL FACILITIES FOR CLIMATE CHANGE

The Office of Budget Management should work with City departments to prioritize upgrades to municipal buildings in Downtown exposed to stormwater flooding in the near term or to flooding at 9 inches of SLR under a 1 percent annual chance flood event. EMS Station Ambulance 8 will be exposed to coastal flooding at 9 inches of SLR under a 1 percent annual chance flood event. The South Postal Station on Atlantic Avenue will be exposed to stormwater flooding in the near term and coastal flooding from the 1 percent annual chance event in the second half of the century. To address extreme heat risks, the City should prioritize backup power installation at municipal facilities that demonstrate high levels of criticality, including specific Boston Centers for Youth and Family and Boston Public School facilities that serve as emergency shelters.

East Boston

East Boston, located to the northeast, across from Charlestown and Downtown Boston, is bounded by tidal portions of Chelsea Creek, the Mystic River, and Boston Harbor.

East Boston is composed of five separate islands connected by fill. The first two islands, Noddle's and Hog's Islands, were joined during the eighteenth century, and the others, Governor's, Bird, and Apple, were connected during the 1940s to support the growth of Logan Airport. In 1833, William Sumner established the East Boston Company to develop East Boston as a planned community. East Boston was annexed by Boston in 1836. From 1840 onward, it experienced rapid growth, fueled by marine industrial activity along the waterfront, particularly the construction of clipper ships. Logan Airport was built in the early 1920s and has experienced significant expansion over time, especially during the 1960s and 1970s.

Today, East Boston is home to a mix of residential neighborhoods, commercial areas, and major regional transportation assets, including Logan Airport. East Boston is bisected by Route 1A/ McClellan Highway and Interstate 90 and has four major tunnels. The Sumner and Callahan Tunnels carry Route 1A under Boston Harbor, connecting Downtown and East Boston, with the Callahan carrying northbound traffic and the Sumner carrying southbound traffic. The Ted Williams Tunnel carries I-90 under Boston Harbor, connecting South Boston to Logan Airport and providing a route for the Silver Line. The East Boston Tunnel carries the Blue Line from the Aquarium MBTA Station in Downtown to the Maverick Station in East Boston.

East Boston includes four major commercial areas, including Maverick Square to the south, Central Square at the edge of the Inner Harbor, Day Square near the Chelsea Street Bridge, and Orient Heights to the north. In addition, East Boston includes some industrial areas along the waterfront, particularly Chelsea Creek. The community also includes important recreational and natural areas, including the East Boston Greenway, Constitution Beach, and Belle Isle Marsh, the largest remaining salt marsh in Boston.

East Boston is currently a neighborhood in transition, as demonstrated by strong recent income growth and development activity. It has experienced an influx of young professionals, especially in Maverick Square, along Jeffries Point, and along the Eagle Hill waterfront. The waterfront has been evolving into a mixed-use environment, with new residential and open-space development. Since 2000, almost 300 new residential units have been built, with over 2,000 more either under construction or in the pipeline. The greatest concentration of new development has been along the waterfront, south of Central Square. Logan Airport also has experienced a significant expansion of international flights.

Image courtesy of Sasaki

FLOOD PROGRESSION

DEFINITIONS

Near term: Beginning 2030s, assumes 9 inches of sea level rise

Midterm: Beginning 2050s, assumes 21 inches of sea level rise

Long term: Beginning 2070s or later, assumes 36 inches of sea level rise

Exposure: Can refer to people, buildings, infrastructure, and other resources within areas likely to experience hazard impacts. Does not consider conditions that may prevent or limit impacts.

Vulnerability: Refers to how and why people or assets can be affected by a hazard. Requires site-specific information.

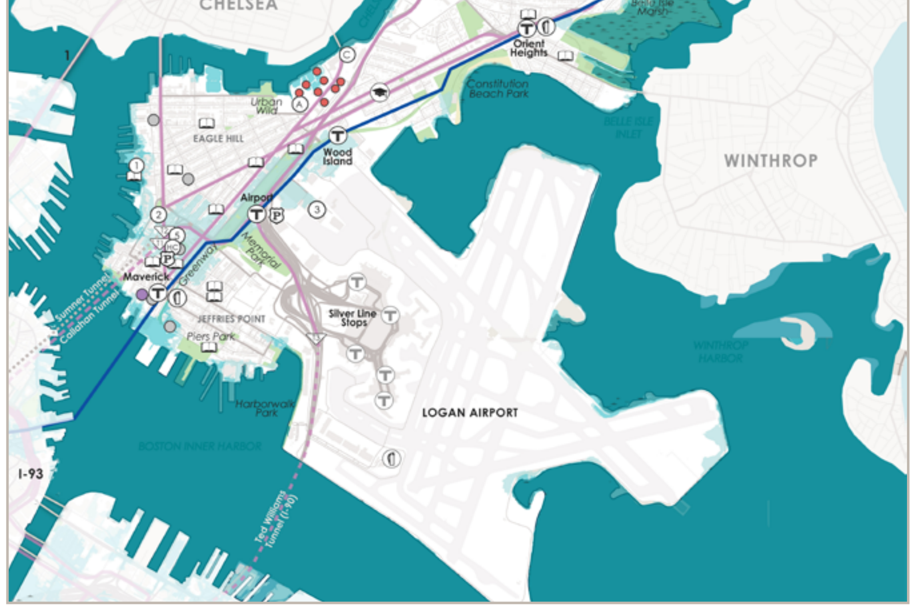
Consequence: Illustrates to what extent people or assets can be expected to be affected by a hazard, as a result of vulnerability and exposure. Consequences can often be communicated in terms of economic losses.

Annualized losses: The sum of the probability-weighted losses for all four flood frequencies analyzed for each sea level rise scenario. Probability-weighted losses are the losses for a single event times the probability of that event occurring in a given year.

*For a full list of definitions, refer to the Glossary in the Appendix.

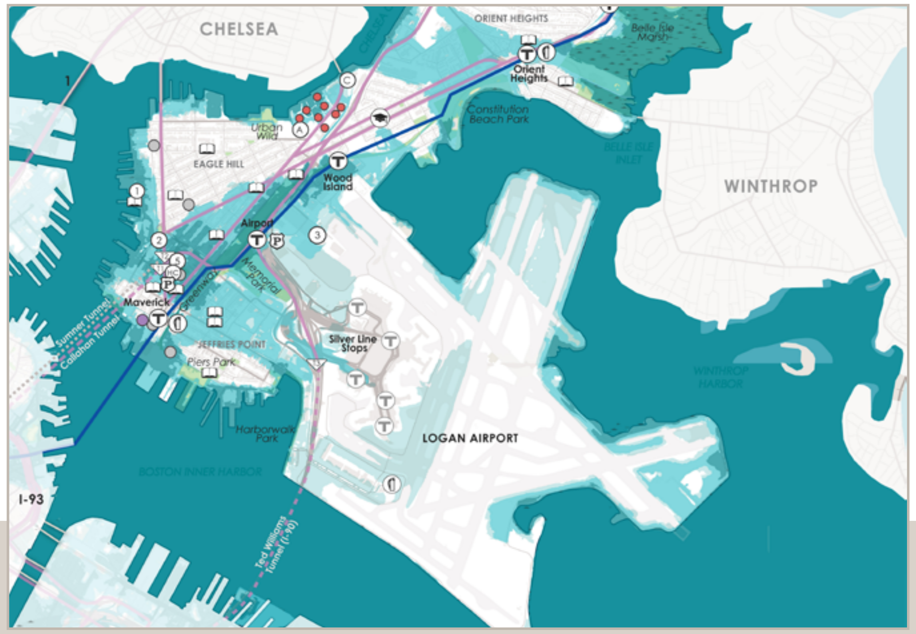
East Boston is exposed to climate change impacts including heat, increased precipitation and stormwater flooding, and sea level rise and coastal and riverine flooding. Exposure to heat and stormwater flooding are addressed in the Citywide Vulnerability Assessment (see p.12), while exposure to and consequences of coastal and riverine flood risk are further discussed in this section.

East Boston has the most land area of all Boston neighborhoods exposed to coastal storms in the coming decades, with exposure concentrated near the East Boston Greenway, Maverick Square, and the Sumner and Callahan Tunnels. Nearly 50 percent of East Boston's land area will be exposed to coastal flooding at the 1 percent annual chance event as soon as the 2070s.



9 INCHES SEA LEVEL RISE

21 INCHES SEA LEVEL RISE



36 INCHES SEA LEVEL RISE

LEGEND

- Average Monthly High Tide
- 10% Annual Chance Storm
- 1% Annual Chance Storm
- Parks
- Roads
- Major Roads
- Major Tunnels
- Evacuation Route
- Evacuation Route Tunnels
- MBTA Blue Line
- MBTA Station
- Sumner & Callahan Tunnel Entrances
- I-90 Tunnel Entrance
- College or University
- School
- Police Station
- Fire Station
- Caruso Pump Station
- Healthcare Center
- Harborside Community Center
- East Boston Community Center
- EMS Station 5 (A7)
- Pino Community Center
- Bulk Oil Storage Facility
- Senior Housing
- Longterm Care Facility
- BHA Public Housing

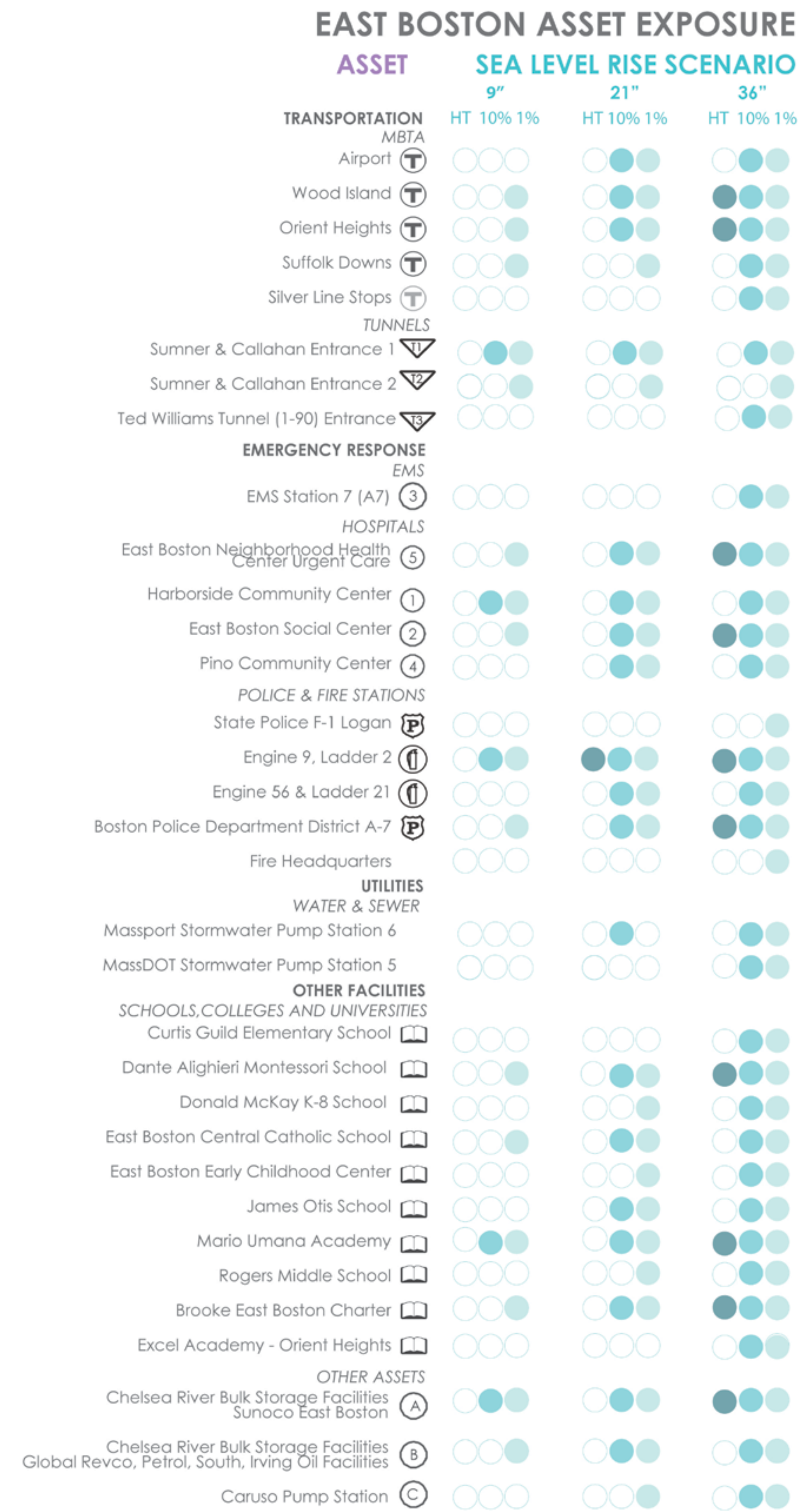
By the end of the century, land area exposed to flooding from coastal storms will more than triple as additional entry points for flooding become present. Along the East Boston Greenway, frequent flooding from high tides will be likely.

Climate resilience planning must consider East Boston's multiple low-lying waterfront edges to address neighborhood exposure as a whole. Nevertheless, the waterfronts near the East Boston Greenway and the Sumner and Callahan Tunnels are exposed in the near term and should be addressed earliest.

Throughout the century, the majority of the East Boston waterfront, parts of Logan Airport, and some inland residential areas are expected to be exposed to sea level rise and coastal storms. In total, 16 percent of the land area in East Boston may be exposed to low-probability flooding in the near term, increasing to almost 50 percent of the neighborhood exposed to low-probability events later in the century.

There are two critical low-lying entry points along the coast that allow for inland flooding in the near term. High-tide flooding expected later in the century may use these same pathways. First, the southern end of East Boston is exposed via the East Boston Greenway (see 1 on map to left). Second, the area south of Bennington Street is exposed by a low point to the west of the Sumner and Callahan tunnel entrances (2). **The two pathways expose the strip adjacent to the East Boston Greenway to inland flooding throughout the century, from the neighborhood's southern waterfront to the Wood Island MBTA Station in the north (3).** Later in the century, flood exposure expands from this area west toward Bennington Street and east toward Logan Airport. In addition, waterfront areas near Harborwalk Park (4) and between Logan Airport and Constitution Beach Park (5) are also projected to be exposed to flooding by many coastal storm events late in the century.

Further north in East Boston, between Orient Heights and Wordsworth Street, both sides of the neighborhood are expected to be exposed to flooding from high-probability storms in the second half of the century (6). Constitution Beach Park (7) and the Chelsea River waterfront (8) will both be exposed during the same time period.



O'Donnell Elementary, East Boston High School, Bradley School not exposed.

Orient Heights BHA Housing not exposed.

EXPOSURE

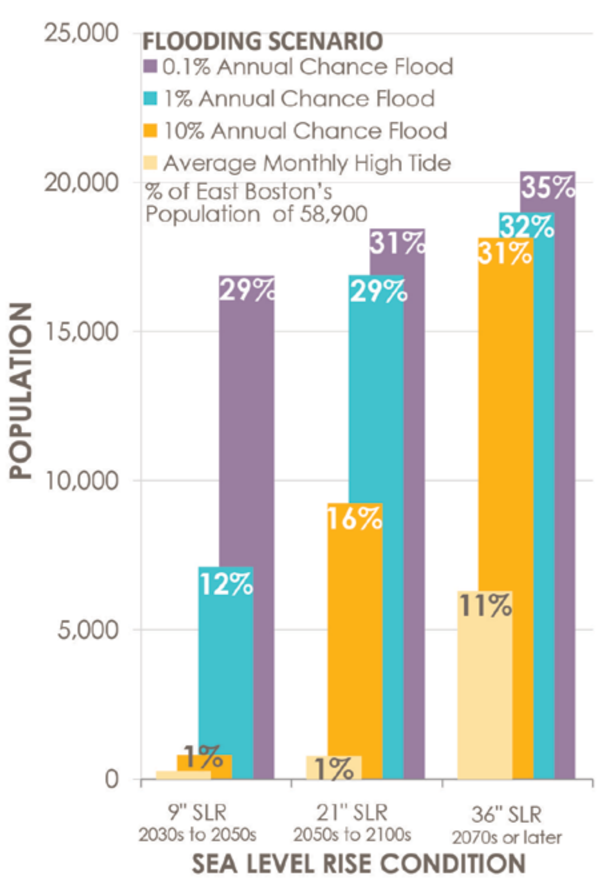
POPULATION & INFRASTRUCTURE

As soon as the 2070s, almost 50 percent of current East Boston residents and parts of Logan Airport will be directly exposed to high-probability coastal flood events (10 percent annual chance).

POPULATION AND SOCIAL VULNERABILITIES

East Boston is currently home to over 40,500 people. **East Boston has high concentrations of different types of socially vulnerable populations, some of the densest within Boston.** The neighborhood is racially diverse, with people of color comprising 63 percent of residents, compared to the citywide average of 53 percent, and over 50 percent of residents are Latino. In particular, 44 percent of residents have limited English proficiency, higher than Boston as a whole.

EAST BOSTON POPULATION EXPOSURE



Close to 300 residents in East Boston could be exposed or displaced by frequent flooding (high tides) in the near term, a number that is expected to skyrocket to over 6,200 people exposed to high tides by the end of the century. This is compared to over 19,000 people exposed to low-probability storms later in the century, almost half of East Boston's population.

Only 14 percent of East Boston's low-income residents own cars, indicating that these populations depend disproportionately on public transportation. The limited availability of vehicular transportation options to East Boston residents indicates a strong need to harden local emergency services and shelter operations against flood impacts. When only flood depths, resident income, and age are considered, East Boston can expect over 1,800 residents to require shelter during and after low-probability storms later in the century. This is second only to South End, whose entire neighborhood will be exposed to coastal storms during the same period. Around 1,300 people are expected to require shelter for low-probability events (1 percent annual chance) expected as soon as the 2050s. East Boston's emergency shelter capacity, 517 people and 96 animals, may not be adequate for the scale of flooding expected in the second half of the century. Furthermore, all of the neighborhood's existing emergency shelters will be exposed to high-probability flood impacts later in the century (10 percent annual chance).

As soon as the 2070s, Boston Housing Authority's Heritage Development along Sumner Street will be exposed to high-probability (10 percent annual chance) flood events.

Image courtesy of Sasaki

INFRASTRUCTURE

East Boston includes many significant transportation assets, including Logan Airport, Interstate 90, Route 1A, and the MBTA Blue and Silver Lines. Critical evacuation routes are exposed to a major storm in all sea level rise scenarios.

Since East Boston is separated from other neighborhoods by Boston Harbor, Boston needs transportation connectivity to enable access to Logan Airport from other neighborhoods and to enable access to healthcare from East Boston. Eight I-90 and Route 1A tunnels' exits and entrances are located within the flood extent for low-probability events in the near term. Flooding of I-90 and Route 1A would present complications to safe evacuation, and avoidance of flooded areas can lead to overstressed and crowded side streets when drivers seek alternate routes.

Four MBTA Blue Line stations and a Silver Line station are also located within future flood extents. If exposed Blue Line stations were rendered inoperable, nearly 14,000 individuals that enter the stations to use the line on an average weekday would be in need of alternative transportation options.[1] The Blue Line's Airport and Wood Island Stations both lie along the low-lying East Boston Greenway and will be exposed to high-probability (10 percent annual chance) floods as soon as the 2050s. Although the Maverick Station is not exposed to coastal and riverine flooding during this century, the Aquarium MBTA Station Downtown is also exposed to high-probability events in the near-term. If the Aquarium Station is rendered inoperable, Blue Line service could be interrupted from Downtown through Revere. Flooded MBTA stations or inundated roads that limit bus mobility represent a concern for East Boston's physical disconnection from the rest of the City, especially for the low-income population without vehicle access.

East Boston's police and fire services will be exposed to severe, lower-probability coastal storms and sea level rise in the late century. East Boston has four fire stations; half will be exposed to low-probability flood events expected as soon as the 2050s, and three will be exposed to low-probability flood events expected as soon as the 2070s, including the Fire Headquarters. Two exposed law enforcement stations make up the entire law enforcement capacity in East Boston, including the Massachusetts state police station at Logan Airport. The state police station will not be exposed until later in the century under low-probability flooding conditions, though the District A-7 station is exposed to lower-probability events in the near term. A proposed multiuse municipal facility—shared by Emergency Medical Services and the Boston Police, Public Works, and Parks and Recreation Departments—will be located just east of the American Legion Playground. While the exact location of the various buildings within the site is still being studied, the adjacent intersection of E. Eagle Street and Eagle Square will be exposed to very low-probability flood events in the late century (0.1 percent annual chance). As East Boston is relatively isolated from the rest of Boston, fire and police assets are essential to maintain emergency response capacity, and site-specific evaluations must be conducted to assess potential vulnerabilities and impacts.

While the pump station serving East Boston's sanitary sewage needs is itself protected against storm surge, inundation of access roads may result in repair delays and periods of interrupted sanitary sewer service.

The Caruso pump station, located to the southwest of the Chelsea Street Bridge along the Chelsea River, serves all of East Boston's sanitary sewage needs. The facility itself is protected against storm surge, but local access roads to the facility are expected to experience flooding during low-probability mid-century events (1 percent annual chance). If the pump station were rendered inoperable, inundated or damaged roads may delay response time of repair crews and result in longer periods of interrupted sanitary sewer service in East Boston.

Exposure to petroleum storage facilities in East Boston may impact Logan Airport operations and other fuel users.

East Boston shares the Chelsea River Bulk Petroleum Storage Facilities site with Chelsea, across the river. Portions of the Sunoco East Boston facility on this site appear to be exposed to high-probability (10 percent annual chance) flooding in the near term and may be exposed to monthly tides later in the century. The Sunoco facility provides jet fuel to Logan Airport for daily operations and home heating fuel for other areas throughout the city. Nevertheless, Massport has identified backup fuel sources for use in emergency situations.

Logan Airport is operated by Massport. Massport has a detailed operational resilience plan for all its assets to ensure safety and continuity of critical operations in the event of a flood. Should a service interruption occur, Massport's level of service planning goal is to restore operations during and after disruptive events as soon as possible in a safe and economically viable time frame, based on asset criticality. The rental car center, portions of Airport Way, and Terminal A are exposed to the high-probability flooding expected as soon as the 2070s, while Terminal E, airport service roads, and portions of runways fall within the flood extents for a low-probability event (1 percent annual chance) in the same time period. Specific assets critical for recovery operations have been protected against flood impacts; protections include redundant generators, emergency pumps, and backup fuel sources. As a key player of East Boston's economy, the resilience of Logan Airport will heavily influence East Boston's recovery after a flood event. Massport's robust planning efforts at Logan Airport in an attempt to address such dependence can serve as an example for other organizations.

[1] Based on 2014 MBTA ridership and service statistics. Number only captures station entries and does not include all passengers traveling on the line as it passes through the station.

EXPOSURE AND CONSEQUENCES

BUILDINGS AND ECONOMY

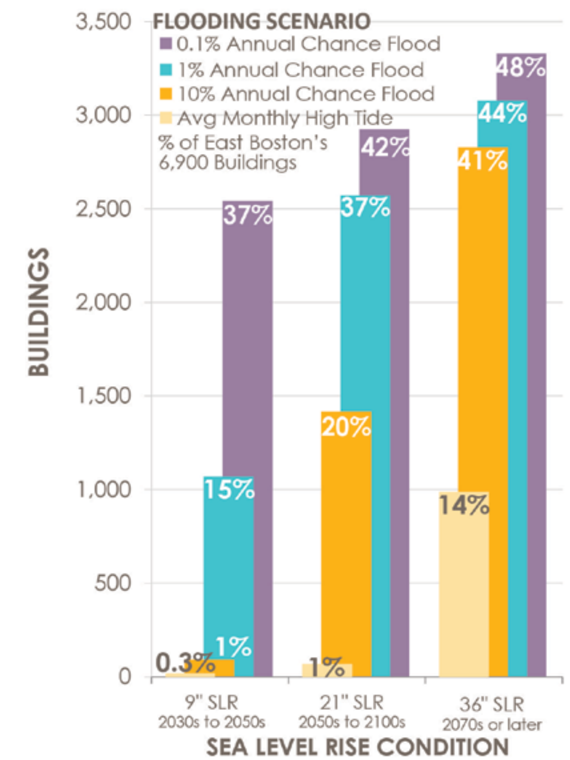
RISK TO BUILDINGS

Throughout the century, about two-thirds of structures and half of the building footprint that are expected to be impacted by coastal flooding are residential or mixed-use in nature.

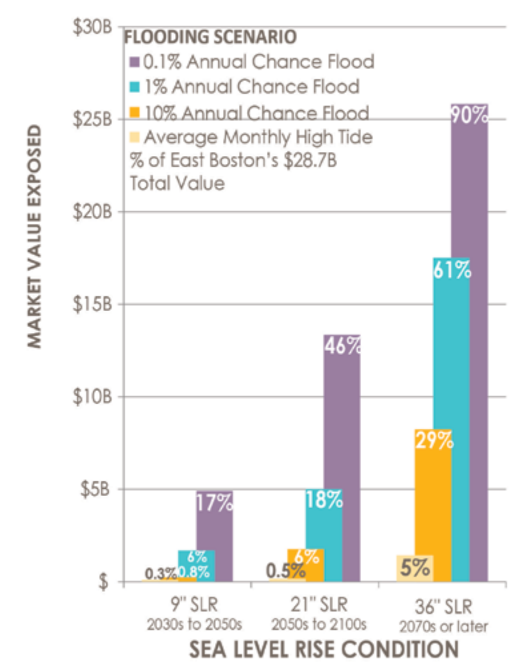
Like Charlestown, the majority of structures in East Boston are one or multifamily residential buildings averaging around three stories tall. Exposure to buildings in East Boston increases rapidly with sea level rise and event severity. For example, in the near term, East Boston represents just 16 percent of all buildings expected to be exposed to high-probability flood events throughout Boston (10 percent annual chance) but increases to 50 percent of all of Boston's buildings exposed to low-probability events. Even with East Boston's high volume of exposed buildings, the neighborhood's real estate market value exposed to low-probability events in the near term is a relatively low share of Boston's exposed real estate for the same time frame (9 percent).

The number of buildings expected to flood at the 1 percent annual chance event triples between the near term and the end of the century. Moreover, East Boston is consistently one of the top neighborhoods with regard to expected physical damage and other flood losses to structures. Expected annualized losses to structures jump from about $11 million to over $80 million between the near term and the second half of the century and could double again in the late century. The extensive amount of inland flooding within East Boston, which enters through specific pathways at the coast, implies that mitigation planning and flood solutions may need to be concentrated at flood entry points on the coast.

EAST BOSTON BUILDING EXPOSURE



EAST BOSTON MARKET VALUE EXPOSURE



More than half of East Boston's building stock will be exposed to flooding from low-probability events as soon as the 2070s. With 3,000 buildings exposed, East Boston is second only to South End for this period.

RISK TO THE ECONOMY

As of 2014, East Boston's local economy produces over $6 billion annually in sales and revenues (output) and sustains over 28,000 jobs. The neighborhood's economy is heavily dependent on Logan Airport and the air transportation industry, which generate almost $2.5 billion in output within East Boston. Logan Airport is New England's largest transportation center and is a major employment hub for Boston, employing approximately 12,000 people. Industries related to air travel, including service-based industries, car rental operations, and hotels, also have a strong presence within East Boston and are responsible for 9 percent of the area's total output.

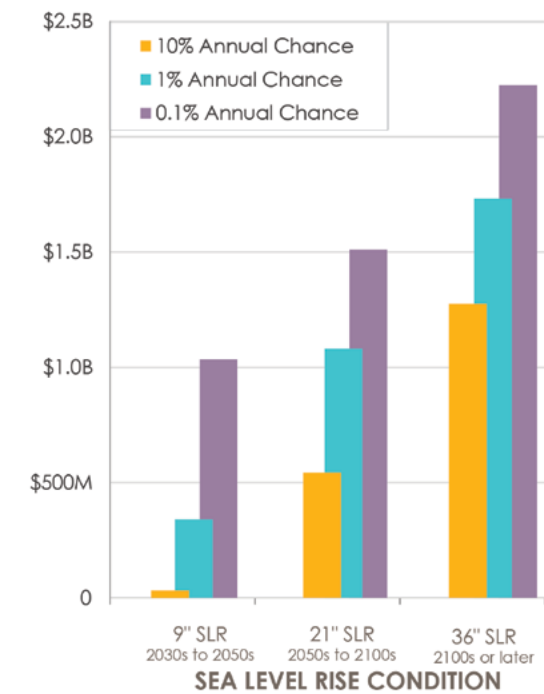
Direct annualized impacts to output in East Boston expected for later in the century are $30.7 million and 270 jobs (see Appendix for detail on methodology). These impacts reflect business operations interrupted after flooding while structures are repaired or businesses relocate. With indirect and induced annual economic impacts included, covering interrupted operations to businesses tied to East Boston's economy, losses could increase by another $12.6 million and 63 jobs. Totaling direct, indirect, and induced impacts, the total annualized effect associated with flooding expected later in the century is $43.3 million and 330 jobs, 19 percent of total losses for the neighborhood. Key industries affected by these losses include the food services sector, the transportation sector, and the accommodations sector, which provide 47 percent of East Boston's jobs and employ predominantly middle- and low-income workers.

ECONOMIC RISK ASSUMPTIONS

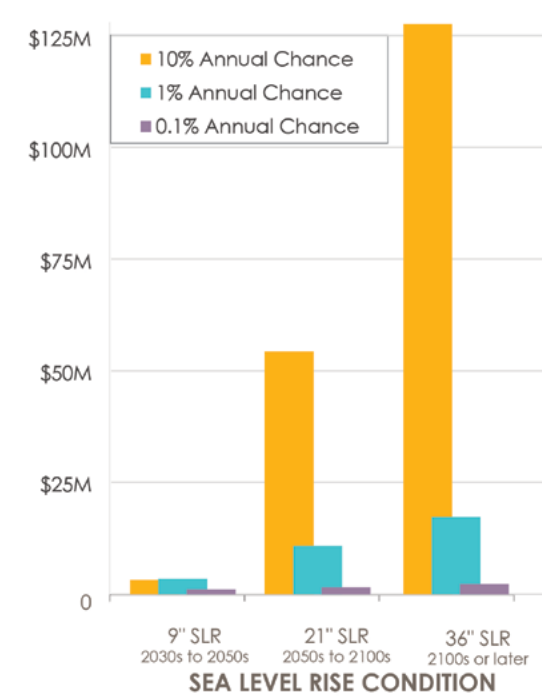
Job and output loss includes direct, indirect, and induced consequences of flood impacts. Direct results are impacts felt within a neighborhood, while indirect and induced results are those expected to be felt throughout Suffolk County as a result of changes in spending patterns. Results for both job and output losses are the sum of annualized values for the four flood frequencies analyzed for each sea level rise scenario. This represents a lower-bound estimate for several reasons. First, not all probabilistic events are considered. Second, the analysis assumes that all impacted businesses eventually reopen, though FEMA estimates that almost 40 percent of small businesses—and up to 25 percent of all businesses—never reopen after experiencing flood impacts. Third, only building areas directly impacted by floodwater are assumed to experience business interruption. This does not consider interruptions of businesses due to loss of power or utility functions. Finally, the analysis only considers existing populations, businesses, and buildings and does not include projections for future growth. Refer to the Appendix for a more detailed explanation of the exposure and consequence analysis.

INDUSTRY	ANNUALIZED LOSS OF ECONOMIC OUTPUT
Restaurants	$10,800,000
Insurance activities	$7,400,000
Transportation	$3,800,000
Remaining industries	$21,300,000
Total	**$43,400,000**

EAST BOSTON ECONOMIC LOSSES



EAST BOSTON ANNUALIZED LOSSES



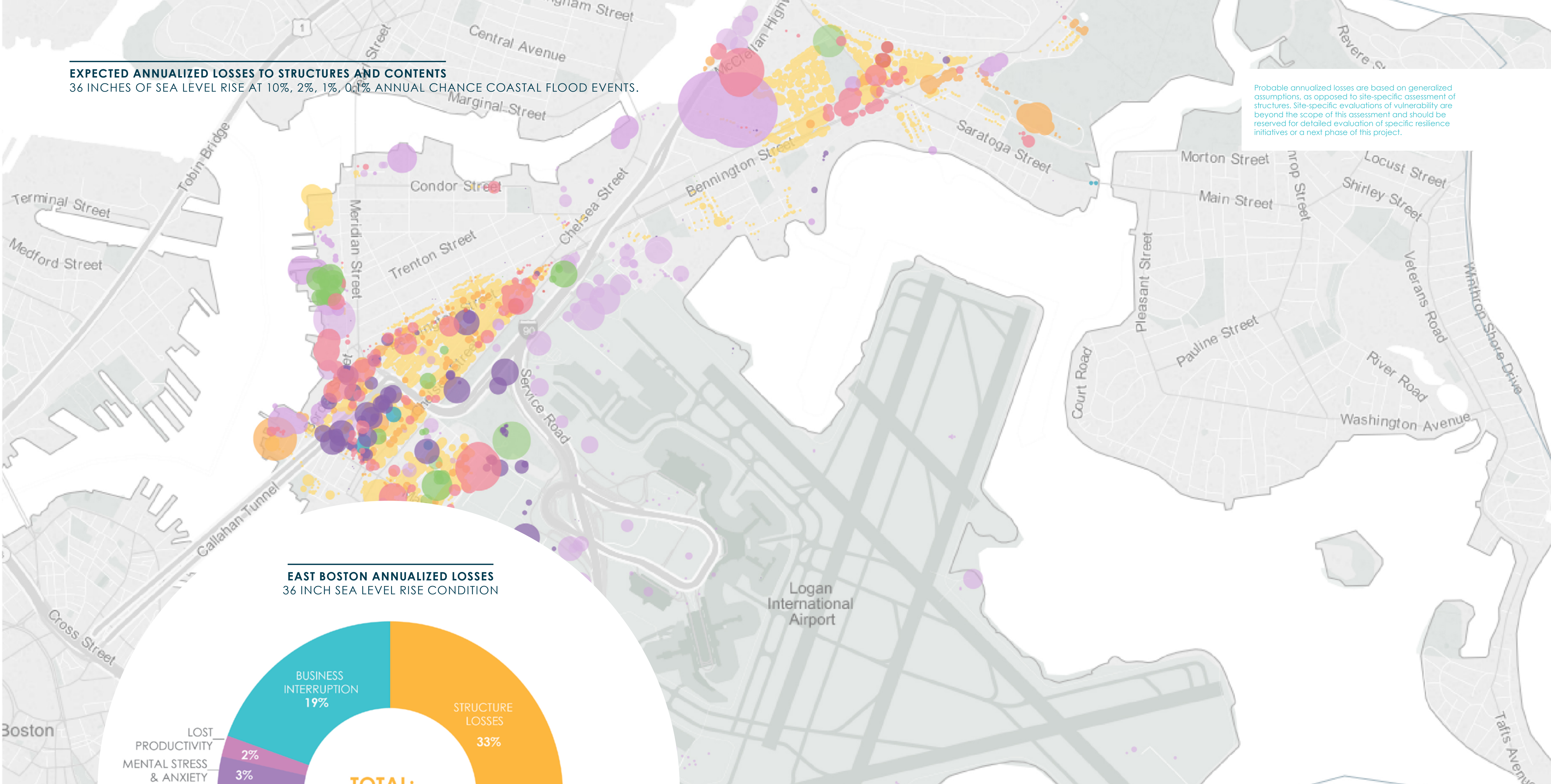
Tremendous recent and planned residential development activity has contributed to population growth in the neighborhood, especially along the vulnerable waterfront.

Two of the top ten structures with the most annual damages expected for later in the century include recent or planned developments for high-occupancy mixed-use buildings.

41 percent of East Boston's building stock is projected to have a 10 percent annual chance of being impacted. Of those buildings, almost 2,300 are residential or mixed-use and house approximately 18,500 people.

EXPECTED ANNUALIZED LOSSES TO STRUCTURES AND CONTENTS

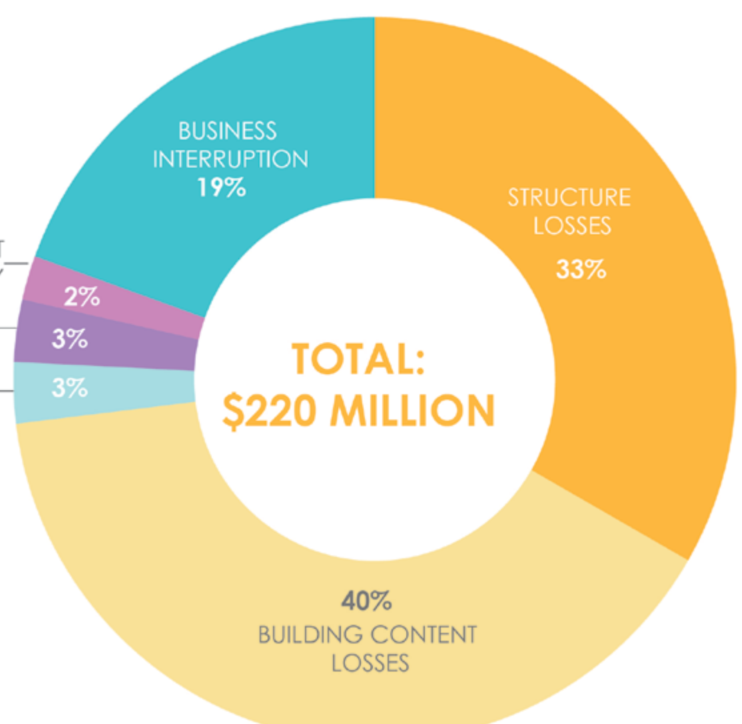
36 INCHES OF SEA LEVEL RISE AT 10%, 2%, 1%, 0.1% ANNUAL CHANCE COASTAL FLOOD EVENTS.



Probable annualized losses are based on generalized assumptions, as opposed to site-specific assessment of structures. Site-specific evaluations of vulnerability are beyond the scope of this assessment and should be reserved for detailed evaluation of specific resilience initiatives or a next phase of this project.

EAST BOSTON ANNUALIZED LOSSES

36 INCH SEA LEVEL RISE CONDITION



- Commercial ($23M)
- Cultural/Religious, Edu, Rec ($16M)
- Essential Services ($13.9M)
- General Government ($.7M)
- Industrial/Transportation($33.2M)
- Mixed Use ($14.5M)
- Residential ($71.6M)

Total ($173M)

$5.0M $4.0M $3.0M $2.0M $1.0M

Each circle represents annualized losses suffered by an individual building. Larger circle size indicates higher contents and structures losses. Annualized losses take into consideration the annual probability of an event occurring, as well as the projected impacts of such an event.

PROTECTED SHORES

DEVELOP LOCAL CLIMATE RESILIENCE PLANS TO SUPPORT DISTRICT-SCALE CLIMATE ADAPTATION

The City should develop a local climate resilience plan for East Boston to support district-scale climate adaptation. The plan should include the following:

- **Community engagement** through a local climate resilience committee, leveraging existing community-led organizations and efforts in East Boston, including the ClimateCARE effort being led by Neighborhood of Affordable Housing (NOAH).
- **Land-use planning for future flood protection systems**, including Flood Protection Overlay Districts in strategically important "flood breach points" identified below (see Potential Flood Protection Locations).
- **Flood protection feasibility studies,** evaluating district-scale flood protection, including at locations identified below (see Potential Flood Protection Locations).
- **Infrastructure adaptation planning** through the Infrastructure Coordination Committee. For East Boston, the Massachusetts Port Authority (Massport) is a key partner, and it has already undertaken significant adaptation planning for its buildings, infrastructure, and operations related to Logan.
- **Coordination with other plans**, including Imagine Boston 2030, GoBoston 2030, Special Planning Areas, and any updates to the East Boston Municipal Harbor Plan.
- **Development of financing strategies and governance structures** to support district-scale adaptation.

ESTABLISH FLOOD PROTECTION OVERLAY DISTRICTS AND REQUIRE POTENTIAL INTEGRATION WITH FLOOD PROTECTION

The Boston Planning and Development Agency (BPDA) should petition the Boston Zoning Commission to create new Flood Protection Overlay Districts in areas that are strategically important for potential future flood protection infrastructure (see Potential Flood Protection Locations below). Within a Flood Protection Overlay District, a developer would be required to submit a study of how a proposed project could be integrated into a future flood protection system; options may include raising and reinforcing the development site or providing room for a future easement across the site.

PRIORITIZE AND STUDY THE FEASIBILITY OF DISTRICT-SCALE FLOOD PROTECTION

To reduce the risk of coastal flooding at major inundation points, the City should study the feasibility of constructing district-scale flood protection at the primary flood entry points in East Boston (see Potential Flood Protection Locations below for a preliminary identification of locations and potential benefits).

These feasibility studies should take place in the context of local climate resilience plans, featuring engagement with local community stakeholders, coordination with infrastructure adaptation, and considerations of how flood protection would impact or be impacted by neighborhood character and growth. Examples of prioritization criteria include the timing of flood risk, consequences for people and economy, social equity, financial feasibility, and potential for additional benefits beyond flood risk reduction.

POTENTIAL DISTRICT-SCALE FLOOD PROTECTION LOCATIONS[2]

See the District-Scale Flood Protection Systems Overview section (p.330) for a citywide perspective on district-scale flood protection. District-scale flood protection is only one piece of a multilayered solution that includes prepared and connected communities, resilient infrastructure, and adapted buildings.

In the near term, flood protection between Jeffries Point and Central Square is critical to address flood entry points along the western and southern edges of the East Boston waterfront.

As sea level rise (SLR) progresses, additional locations, which would provide modest flood protection in the near term, will become critical:

- By **Porzio Park,** addressing flood entry points near where Jeffries Point meets Logan Airport
- By **Wood Island,** addressing flood entry points along the northern edge of Logan Airport, just east of the Wood Island T Station
- By **Orient Heights,** addressing flood entry points near Constitution Beach and along Chelsea Creek

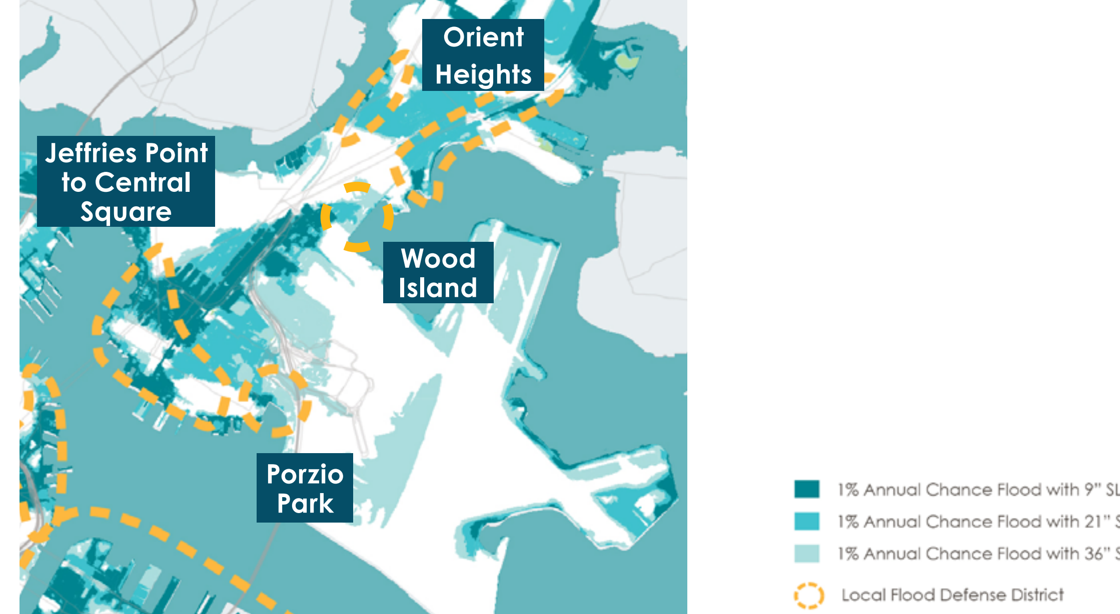
SLR SCENARIO	DISTRICT SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD[3]
9" SLR (2030s–2050s)	Jeffries Point to Central Square
21" SLR (2050s–2100s)	Jeffries Point to Central Square and Porzio Park combined and Orient Heights
36" SLR (2070s or later)	All locations combined

LOCATIONS

- **The Jeffries Point to Central Square location** focuses on flood entry points along the western and southern edges of the waterfront. Potential flood protection solutions could consist of a north/south alignment connecting high points near Central Square and LoPresti Park and an east/west alignment connecting high points at Maverick Square and Jeffries Point. The north/south segment could potentially tie into existing green space at LoPresti Park and could help create new waterfront access points along East Boston's western edge. The east/west segment could potentially tie into existing and planned open spaces along the southern waterfront, such as Piers Park, Brophy Park, and Porzio Park.
- **The Porzio Park location** focuses on a flood entry point near where Jeffries Point meets Logan Airport. Potential flood protection solutions could connect high points at Sumner Street and Harborside Drive, near the entrance to the Ted Williams Tunnel, with the potential to tie in to existing green space along Massport's Harborwalk Park.
- **The Wood Island location** focuses on flood entry points along the northern edge of Logan Airport, just east of the Wood Island T Station. Potential flood protection solutions could connect high points along Belle Isle Inlet to the northern part of Logan Airport, with the potential to tie into existing green spaces at Constitution Beach or Wood Island Bay Edge Park.

[2]These preliminary coastal flood protection concepts are based on a high-level analysis of existing topography, rights-of-way, and urban and environmental conditions. Important additional factors, including existing drainage systems, underground transportation and utility structures, soil conditions, and zoning, as well as any potential external impacts as a result of the project have not been studied in detail. As described in Initiatives 5-2 and 5-3, detailed feasibility studies, including appropriate public and stakeholder engagement, are required in order to better understand the costs and benefits of flood protection in each location.

[3]Additional flood protection may be required for flood events more severe than the 1 percent annual chance flood. See Appendix for more detailed information on expected effectiveness of flood protection systems, including analysis of additional flood protection locations and flood frequencies.



- **The Orient Heights location** focuses on flood entry points near Constitution Beach and along Chelsea Creek. Potential flood protection solutions could consist of two segments: an eastern segment by Constitution Beach, connecting high points near Byron Street and Barnes Avenue, and a western segment by Chelsea Creek, connecting high points near Boardman Street and Eagle Street.

DETAILED CONSIDERATIONS

- **Multiple alignments likely needed in the second half of the century:** With 9 inches of sea level rise (SLR), flood protection between Jeffries Point and Central Square may provide substantial protection against severe, low-probability floods (1 percent annual chance). Adding protection by Porzio Park would be necessary to protect against low-probability (1 percent annual chance) events with 21 inches of SLR, meaning that they do not provide substantial protection from floodwaters on their own. Flood pathways from these locations become connected at the 1 percent annual chance event with 21 inches of SLR, necessitating review to determine whether both measures would be required to prevent extensive flooding. Very low-probability (0.1 percent annual chance) storms expected mid-century may require interventions by Wood Island to prevent flood pathway connections from Logan Airport. Considering 36 inches of LR, flood protection from Jeffries Point to Central Square, by Porzio Park, and by Wood Island will be necessary to protect large portions of East Boston from high-probability events (10 percent annual chance). Nevertheless, stronger events with lower probability of occurrence may find a possible flood pathway from Constitution Beach. Interventions by Orient Heights may be necessary to prevent flooding in the southern portion of East Boston for the 2 percent annual chance event with 36 inches of SLR.
- **Protection of Logan Airport:** Portions of Logan Airport may also benefit from combined flood protection at the four locations identified above. Additional flood protection along the Boston Inner Harbor and Boston Main Channel would serve to protect the majority of flooding expected at Logan later in the century.

PREPARED & CONNECTED COMMUNITIES

CONDUCT AN OUTREACH CAMPAIGN TO PRIVATE FACILITIES THAT SERVE VULNERABLE POPULATIONS TO ENSURE THAT THEY ENGAGE IN EMERGENCY PREPAREDNESS AND ADAPTATION PLANNING

The City should conduct outreach to managers of facilities in East Boston that serve significant concentrations of vulnerable populations and are not required to have operational preparedness and evacuation plans under current regulations. Targeted facilities will include affordable housing complexes, substance abuse treatment centers, daycare facilities, food pantries, small nonprofit offices, and others. Illustrative examples of the types of facilities to which the City might conduct outreach include the East Boston YMCA, East Boston Head Start/Elbow child care facility, and East Boston Neighborhood Health Center. These facilities are exposed to near-term damage from sea level rise and coastal flooding, in addition to access issues related to near-term stormwater flooding.[4] The City may be able to partner with the Neighborhood of Affordable Housing (NOAH) on this outreach, given their extensive resilience education efforts to date.

EXPAND BOSTON'S SMALL BUSINESS PREPAREDNESS PROGRAM

The City should reach out to small businesses in East Boston exposed to stormwater flooding in the near term or coastal flooding under a 1 percent annual chance event at 9 inches of SLR to help them develop business continuity plans, evaluate insurance coverage needs, and identify low-cost physical adaptations. All four of East Boston's major commercial districts (Maverick Square, Central Square, Day Square, and Orient Heights) lie within the 9-inch floodplain. Under a 1 percent annual chance event with 9 inches of SLR, 83 commercial buildings and 133 mixed-use buildings that could host small businesses are exposed to flood risk.

[4]The City did not review the extent of existing preparedness planning as part of this study.

RESILIENT INFRASTRUCTURE

ESTABLISH INFRASTRUCTURE COORDINATION COMMITTEE

The Infrastructure Coordination Committee (ICC) should support coordinated adaptation planning for East Boston's key infrastructure systems, including transportation, water and sewer, energy, telecommunications, and environmental assets. In the near term, the City should support the MBTA in conducting its planned asset-level vulnerability assessment of the Blue Line, which is highly exposed to flooding. At 9 inches of SLR, the Wood Island, Orient Heights, and Suffolk Downs stops are exposed to flooding under the 1 percent annual chance event. At 21 inches of SLR, four of East Boston's five Blue Line stops are exposed to flooding at the 1 percent annual chance event. The City also should support MassDOT in pursuing adaptation plans for Central Artery and tunnel assets developed under the 2015 FHA/MassDOT vulnerability assessment.

CONDUCT FEASIBILITY STUDIES FOR COMMUNITY ENERGY SOLUTIONS

The 2016 Boston Community Energy Study identified Central Square as a potential location for an emergency microgrid, based on its concentration of critical facilities. The Environment Department should work with local stakeholders and utility providers to explore this location, recognizing that portions of the proposed site are exposed to high-probability coastal flooding in the near term, as well as stormwater flooding. The Environment Department also should work with the Massachusetts Port Authority to evaluate opportunities for an expansion of the existing solar power capacity at Logan Airport, given that the 2016 Boston Community Energy Study identified it as having high solar generation potential.

ADAPTED BUILDINGS

PROMOTE CLIMATE READINESS FOR PROJECTS IN THE DEVELOPMENT PIPELINE

Upon amending the zoning code to support climate readiness (see Initiative 9-2, p.135), the Boston Planning and Development Agency (BPDA) should immediately notify all developers with projects in the development pipeline in the future floodplain that they may alter their plans in a manner consistent with the zoning amendments (e.g., elevating their first-floor ceilings without violating building height limits), without needing to restart the BPDA permitting process. Currently, 56 residential and 18 commercial buildings are under construction or permitted in East Boston, representing 2,111 additional housing units and 85,000 SF of new commercial space.

INCORPORATE FUTURE CLIMATE CONDITIONS INTO AREA PLANS AND ZONING AMENDMENTS

The Boston Planning and Development Agency should incorporate future climate considerations (long-term projections for extreme heat, stormwater flooding, and coastal and riverine flooding) into major planning efforts in East Boston.

ESTABLISH A CLIMATE READY BUILDINGS EDUCATION PROGRAM FOR PROPERTY OWNERS, SUPPORTED BY A RESILIENCE AUDIT PROGRAM

The City should develop and run a Climate Ready Buildings Education Program and a resilience audit program to inform property owners about their current and future climate risks and actions they can undertake to address these risks. To prepare for the most immediate risks, the City should prioritize audits for buildings with at least a 1 percent annual chance of exposure to coastal and riverine flooding in the near term, under 9 inches of sea level rise. In East Boston, this includes 1,069 structures, with 74 percent of these consisting of residential and mixed-use buildings that house residents. A resilience audit should help property owners identify cost-effective, building-specific improvements to reduce flood risk, such as backflow preventers, elevation of critical equipment, and deployable flood barriers; promote interventions that address stormwater runoff or the urban heat island effect, such as green roofs or "cool roofs" that reflect heat; and encourage owners to develop operational preparedness plans and secure appropriate insurance coverage. The resilience audit program should include a combination of mandatory and voluntary, market-based and subsidized elements.

PREPARE MUNICIPAL FACILITIES FOR CLIMATE CHANGE

The Office of Budget Management should work with City departments to prioritize upgrades to municipal facilities in East Boston that demonstrate high levels of vulnerability (in terms of the timing and extent of exposure), consequences of partial or full failure, and criticality (with highest priority for impacts on life and safety) from coastal flooding in the near term. In the near term, at 9 inches of SLR, Fire Department Engine 9 (Ladder 2), Boston Police Department District A-7, Mario Umana Academy, and BHA's Heritage housing complex are exposed to flooding under the 1 percent annual flood event. To address extreme heat risks, the City should prioritize backup power installation at municipal facilities that demonstrate high levels of criticality, including specific Boston Centers for Youth and Family and Boston Public School facilities that serve as emergency shelters.

Roxbury

71,600
CURRENT RESIDENTS

10,000
BUILDINGS

24,800
JOBS

$4.2 Billion
ANNUAL ECONOMIC OUTPUT

ROXBURY TODAY

Roxbury, at the geographic center of Boston, began as a farming town on the outskirts of Boston and then transitioned to industrial and residential uses in the early nineteenth century. In the early twentieth century, Roxbury experienced waves of immigration, and in the 1940s and 1950s, it became a center for African Americans migrating from the American South.

Today Roxbury is home to a diverse community. Roxbury is a center for families, with more households with children under five than any neighborhood in Boston. In addition, compared to other neighborhoods in the city, Roxbury has disproportionately high concentrations of people of color, low- to no-income residents, and people with disabilities.

Today, Roxbury has almost 28,000 housing units, about half of which are subsidized housing, and about 400 new units under construction or approved. Roxbury has active neighborhood groups who engage the community in both development and preservation efforts. Roxbury has over 24,000 jobs concentrated in the healthcare, local government, and education sectors. Roxbury Community College and Boston Public Schools are key neighborhood employers. However, many of Roxbury's lower-income residents work in service industry jobs and may depend on public transit to commute to jobs all over the city and region. Dudley Square has long been a commercial hub for the area and serves as a transit hub for a number of MBTA buses and the Silver Line.

While Roxbury includes several parks that offer residents substantial green space, including Franklin Park, its status as a dense, urban neighborhood with a lack of tree coverage in some areas contributes to urban heat island effect. Its inland location away from cooling coastal breezes also adds to higher summer temperatures. Heat island analysis reveals that Roxbury has some of the hottest daytime temperatures in the City of Boston during summer months.

22,000
OLDER ADULTS & CHILDREN*

29%
LOW-TO-NO INCOME RESIDENTS

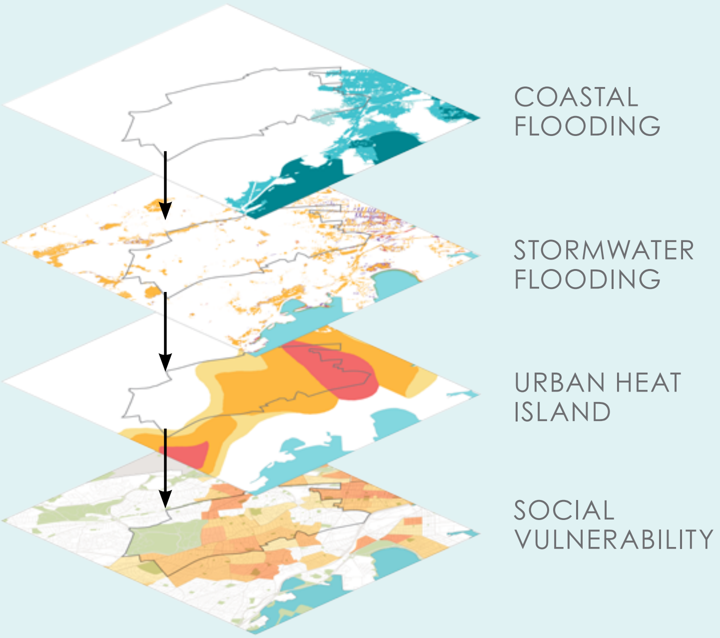
950
BUILDINGS EXPOSED TO STORMWATER FLOODING**

180 acres
LAND AREA FLOODED BY STORMWATER**

*HEAT VULNERABLE **LATE CENTURY SCENARIO

ROXBURY IMPACTS & RISK FACTORS

Roxbury, like many neighborhoods in Boston, is at the convergence of several future climate hazards and vulnerabilities.



CLIMATE HAZARDS

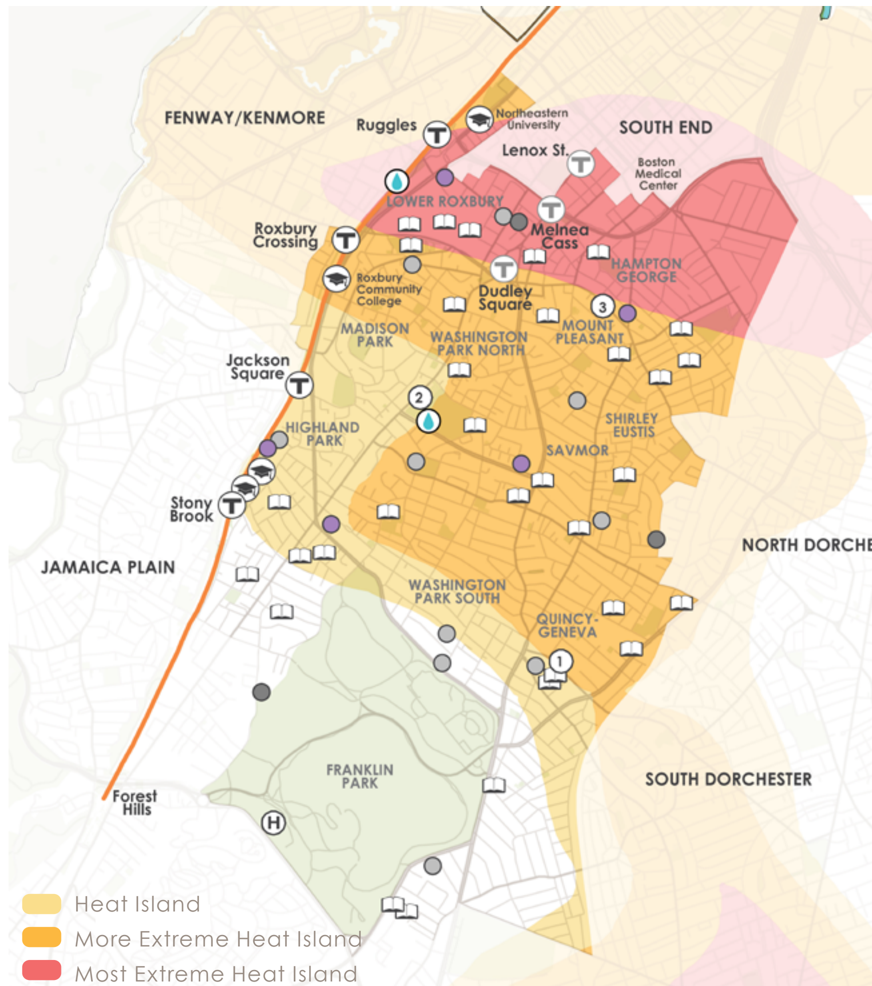
Roxbury faces multiple vulnerabilities and is exposed to coastal and stormwater flooding and extreme heat.

Roxbury has some of the highest poverty rates in all of Boston.

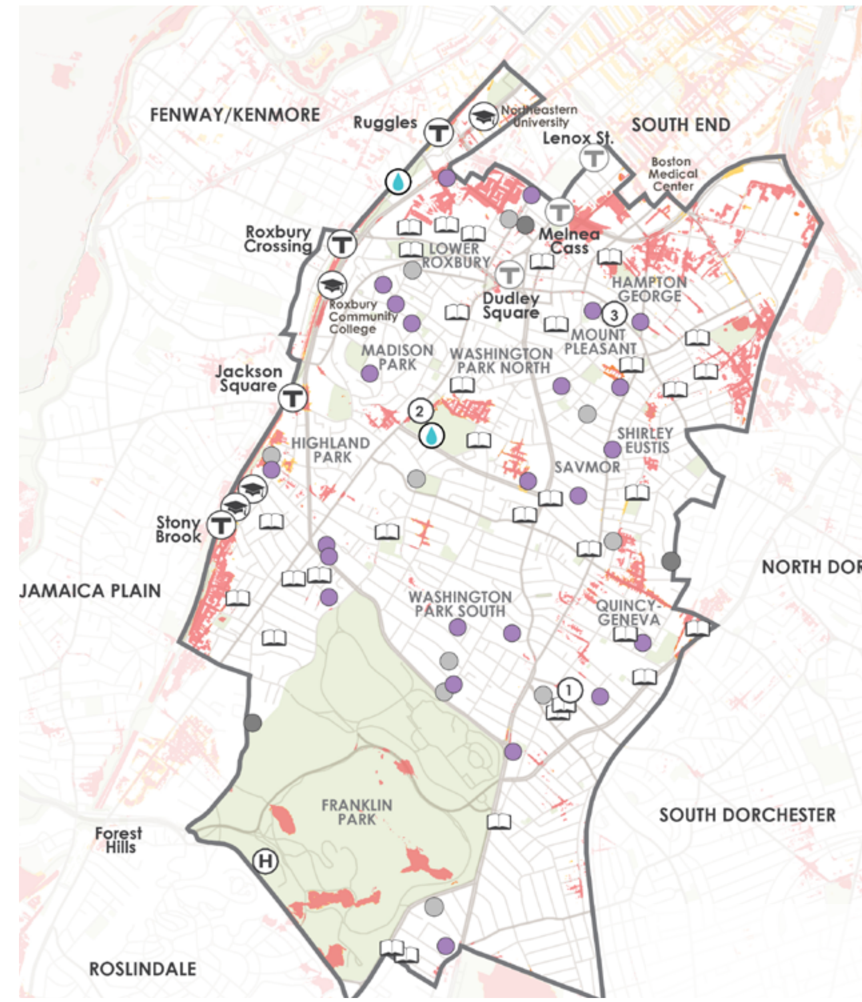
Roxbury's road infrastructure faces significant risk for disruption by stormwater flooding in a 10 year, 24 hour storm in the future.

180 acres of land (6% of total land area) are at risk for flooding in the long-term.

URBAN HEAT ISLAND - 2015



SOCIAL VULNERABILITY OVERLAP



LEGEND

- MBTA Silver Line Station
- MBTA Station
- Roads
- Major Roads
- Evacuation Routes
- Parks
- Roxbury Boundary
- School
- College or University
- Hospital
- Health Clinic
- 1 Grove Hall Community Center
- 2 Shelburne Community Center
- 3 Vine Street Community Center
- BHA Public Housing
- Senior Housing
- DCR Spray Deck or Pool

Roxbury faces risk from several climate hazards. **Today and in the future, stormwater flooding can cause damages and nuisances that create localized challenges for neighborhood mobility and function, and extreme heat endangers residents with vulnerable health.** With 36 inches of sea level rise, coastal storm flooding could reach areas north of Melnea Cass Boulevard

As average temperatures and frequency of heat waves rise in the future, people across Boston will need to seek relief from dangerous extremes more often. Roxbury is one of the **neighborhoods that experience some of the hottest temperatures in the city during summer months.** Lack of tree canopy, a high percentage of impervious surface, and lack of coastal breezes contribute to heat island effect in the neighborhood. Within the heat island areas live many concentrations of populations that are vulnerable to heat including older residents and children.

Roxbury is at risk for stormwater flooding; even today the drainage system can be overwhelmed by heavy rains. More frequent intense storms will cause this type of flooding to increase. The Lower Roxbury and Hampton George areas are expected to experience significant flooding in low-lying areas. Key areas of potential impact include the northern edge of Malcom X Park in Washington Park North as well as the area north of King Towers Public Housing on MLK Boulevard.

Areas on both sides of Melnea Cass Boulevard and surrounding Boston Medical Center are also anticipated to experience stormwater flooding in a 10 year, 24 hour storm. However, this flooding analysis evaluates capacity of the existing drainage system; BWSC is upgrading pipes and expanding system capacity, which will reduce the expected flooding.

Roxbury's population faces multiple vulnerabilities

Roxbury has a richly diverse population; 83% of residents are people of color, the second highest concentration of people of color in the entire city and much higher than Boston as a whole. The vast majority of the population of this neighborhood falls into at least one vulnerable category and most fall into several categories described below.

Roxbury is a stressed neighborhood in many ways. Lack of high quality transportation and fewer redundancies in transportation options in many areas of the neighborhood can strain Roxbury's households in getting to and from employment and in accessing healthcare resources. The Orange Line runs along the neighborhood's western border and the Silver Line provides high quality service to Dudley Square; however, heavy rail or rapid bus service does not penetrate into the southern portions of the neighborhood. Much of Roxbury is also designated as a food desert by the USDA[1] which creates challenges in accessing healthy food and supplies on a daily basis and for sheltering in place in a climate event.

Roxbury has high concentrations of vulnerable populations, but also many community organizations and non-profits that serve residents. Several Boston Centers for Youth and Families (BCYF) connect residents to resources and information and act as cooling centers. Community development corporations advocate for the neighborhood and develop affordable housing. These organizations help supplement the resource network for residents who have special needs and vulnerabilities and enhance resilience in the community in hazard events

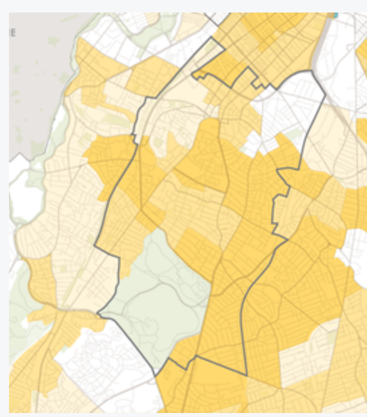
[1]Source: USDA Economic Research Service-Food Access Research Atlas

ROXBURY STATISTICS			
TOTAL POP	71,600	% ROXBURY	% BOSTON
OLDER ADULTS	5,800	8%	10%
CHILDREN	16,690	23%	17%
PEOPLE OF COLOR	59,160	83%	52%
LIMITED ENGLISH	11,400	16%	15%
LOW-TO-NO INCOME	27,690	39%	28%
MEDICAL ILLNESS	24,010	34%	37%
DISABILITY	10,420	15%	11%

VULNERABLE POPULATIONS

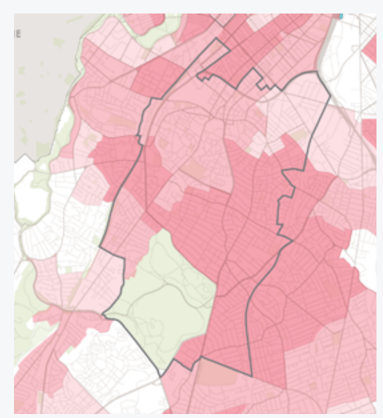
OLDER ADULTS

Roxbury has a lower percentage (8%) of older adults than the city at large (10%), but has ten senior housing developments and three nursing homes within the neighborhood. Care should be taken to educate seniors who live in these developments about the risks of hot weather to their health and to ensure all developments have adequate air conditioning. Shady outdoor locations like public parks can also provide respite during hot days.



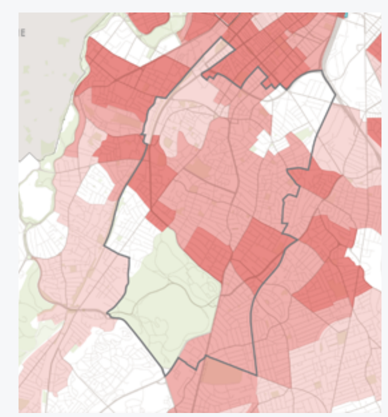
CHILDREN

Roxbury has a relatively high concentration of children; 23% percent of households have at least one child under 5 years old. Children are at risk to the stress of hot temperatures if they do not have adequate access to air conditioned spaces or green spaces to help stay cool. Children also suffer the mental stress of other flooding and other emergencies more than adults. Many children in Roxbury are already bearing the stress of living in an under resourced neighborhood.



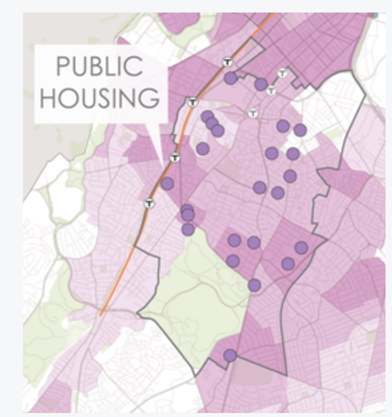
PEOPLE OF COLOR

Roxbury's population is 83% people of color. 35% of residents are black, and the neighborhood is also home to significant Hispanic (22%) and Asian (9%) populations. Roxbury is a rich confluence of many different cultures, but also faces a legacy of racial inequities.



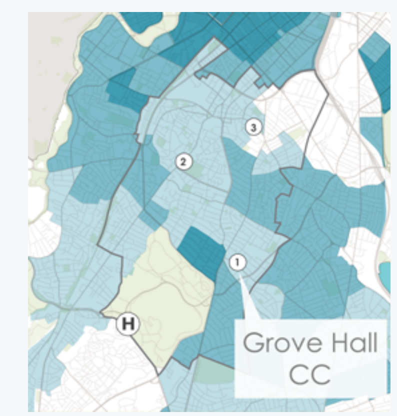
LIMITED ENGLISH

Over 11,000 residents (16% of Roxbury's population) have limited English proficiency and may need targeted information campaigns to increase awareness about climate risks. These residents are fairly spread out throughout the neighborhood. Among those with limited English proficiency, the most common languages spoken are Spanish or Spanish Creole (24%), Chinese (10%), African languages (4%) and Portuguese (3%).



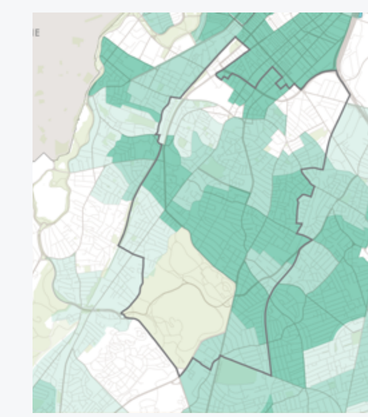
LOW-TO-NO INCOME

39% of Roxbury's population is low-to-no income, and Roxbury has five public housing developments, including the King Towers (100 units) which is projected to experience stormwater flooding from a 10 year, 24 hour storm as early as 2030. Low income residents dependent on public transportation in southern areas of the neighborhood are only served by buses. HUD housing projects as a policy do not include air conditioning in housing units, which increases health risks in a heat wave.



MEDICAL ILLNESS

Medically ill residents in Roxbury may have symptoms worsened by the physical stress of a heat wave. The Washington Park South area has a very high concentration of medically ill. For residents without air conditioning, the cooling center at Grove Hall Community Center is likely the most convenient center. The entire census tract that has the highest concentration of medically ill is within a 3/4 mile radius of the cooling center.



DISABILITIES

15% of Roxbury's population has a disability. That is over 10,000 people who may find it more difficult to evacuate or seek shelter in an extreme weather event (like the 2014 snow storms). Many of this population already face mobility challenges that could be worsened by stormwater flooding on sidewalks. Concentrations are fairly evenly distributed across Roxbury.

Source: USDA Economic Research Service-Food Access Research Atlas

EXPOSURE & CONSEQUENCES

DEFINITIONS

Near-term: Beginning 2030s, assumes 9 inches of sea level rise

Mid-term: Beginning 2050s, assumes 21 inches of sea level rise

Long-term: Beginning 2070s or later, assumes 36 inches of sea level rise
Exposure: Can refer to people, buildings, infrastructure, and other resources within areas likely to experience hazard impacts. Does not consider conditions that may prevent or limit impacts.

Vulnerability: Refers to how and why people or assets can be affected by a hazard. Requires site-specific information.

Consequence: illustrates to what extent people or assets can be expected to be affected by a hazard, as a result of vulnerability and exposure. Consequences can often be communicated in terms of economic losses .

Annualized losses: The sum of the probability-weighted losses for all four flood frequencies analyzed for each sea level rise scenario. Probability-weighted losses are the losses for a single event times the probability of that event occurring in a given year.

*For a full list of definitions, refer to the Glossary in the Appendix.

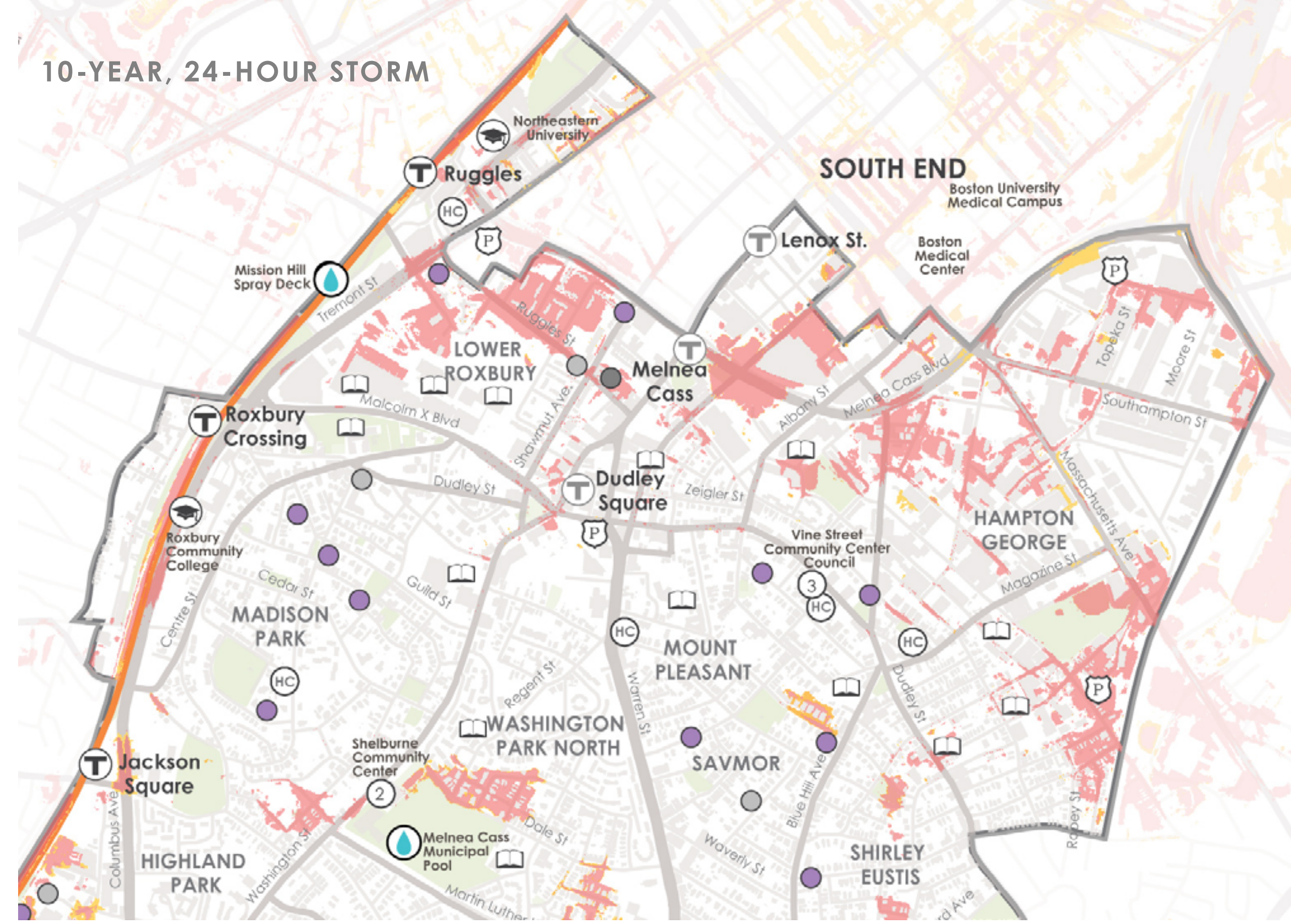
Road disruption by stormwater flooding threatens neighborhood mobility; residential structures face the greatest exposure to flooding

Road flooding can be caused by even a few inches of rain in a short period and can block access to services, force businesses to close, and leave cars and transit riders stranded. Furthermore, flooded roads can be a safety risk when cars attempt to cross flooded areas and become stranded. **Melnea Cass Boulevard is already impacted today in heavy rains and is projected to experience significant flooding at the intersection with Harrison Ave and onto South Bay Harbor Trail.** South of Melnea Cass Boulevard, Hampden and Gerard Streets are also at risk. Melnea Cass flooding will also impact the BWSC headquarters and fueling center.

Projected road flooding impacts several bus routes on Massachusetts Avenue and Melnea Cass Boulevard. Dale Street adjacent to Malcom X Park serves as the access road for the Sojourner House food pantry and could be blocked in a flooding event.

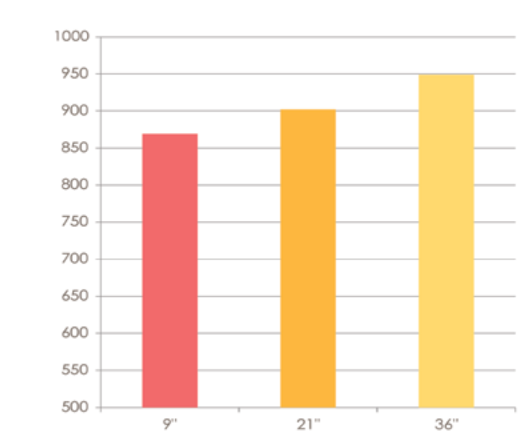
The Amtrak/MBTA rail lines between Tremont and Columbus Avenue are exposed to flooding. The rail lines serve the Amtrak Shore Line and the Orange Line. **Suspended service or lack of access to transit could have serious consequences for Roxbury residents who may not be able to get to work or access healthcare; it also hurts businesses in the area.**

The majority of stormwater impacts to buildings. occur in residential buildings. Stormwater flooding could have strong impacts on indoor air quality from mold, with potential to exacerbate asthma and other health risks. Stormwater flooding is also projected in areas where new development is proposed, including a Northeastern University property slated for new student housing and commercial buildings between Tremont and Columbus Avenue southwest of Douglass Park.

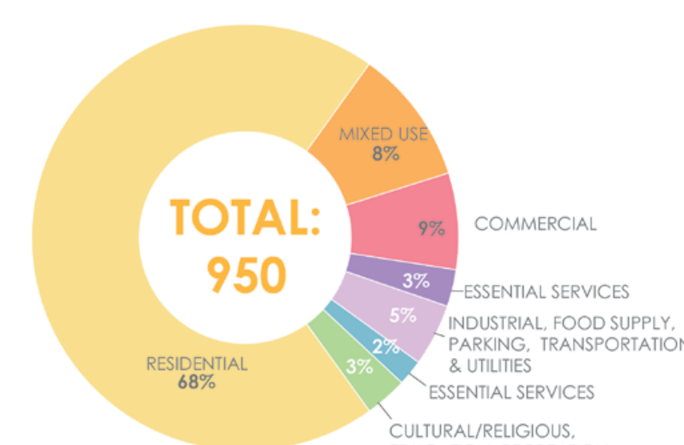


Flood progression into Roxbury takes place through the South End and is described within the vulnerability assessment for that focus area.

BUILDINGS EXPOSED TO STORMWATER FLOODING



ROXBURY BUILDING EXPOSURE TO STORMWATER FLOODING BY TYPE



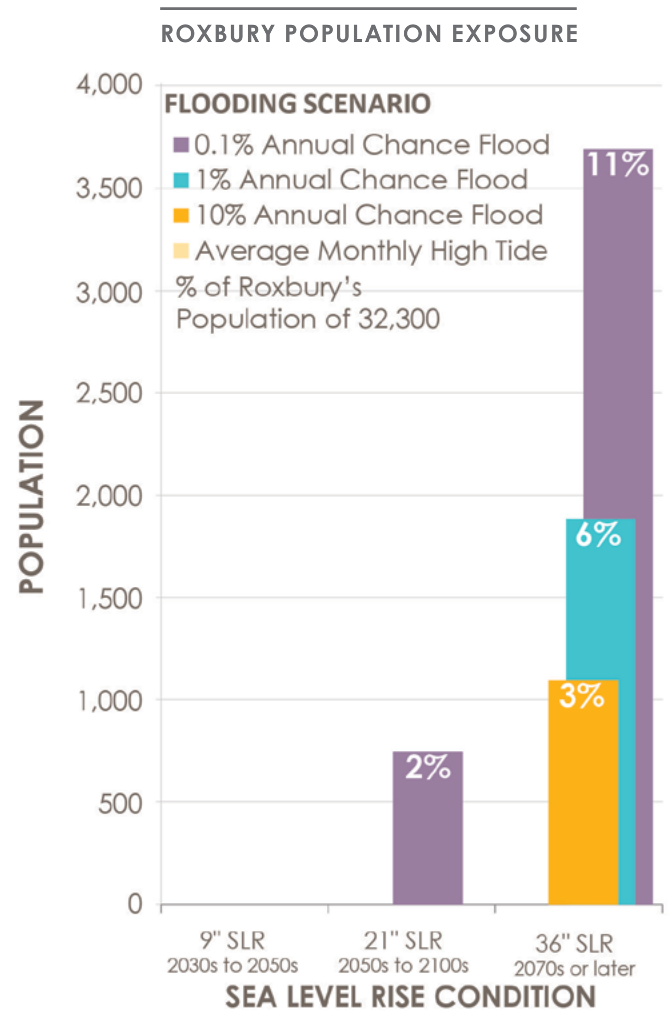
EXPOSURE

POPULATION & INFRASTRUCTURE

POPULATION AND SOCIAL VULNERABILITIES

Roxbury's population is not expected to be exposed to coastal flooding until a very low probability event (0.1 percent annual chance) mid-century. Nevertheless, exposure increases significantly later in the century, and rises to over 1,800 persons currently living in areas exposed to the 1 percent annual chance event. Roxbury's current shelter capacity is 1,300 persons across eight shelters.

Roxbury's population remains largely unexposed to coastal flood impacts until later in the century. The focus area is consistently among the least exposed in terms of land area, population, and buildings when compared to other neighborhoods.



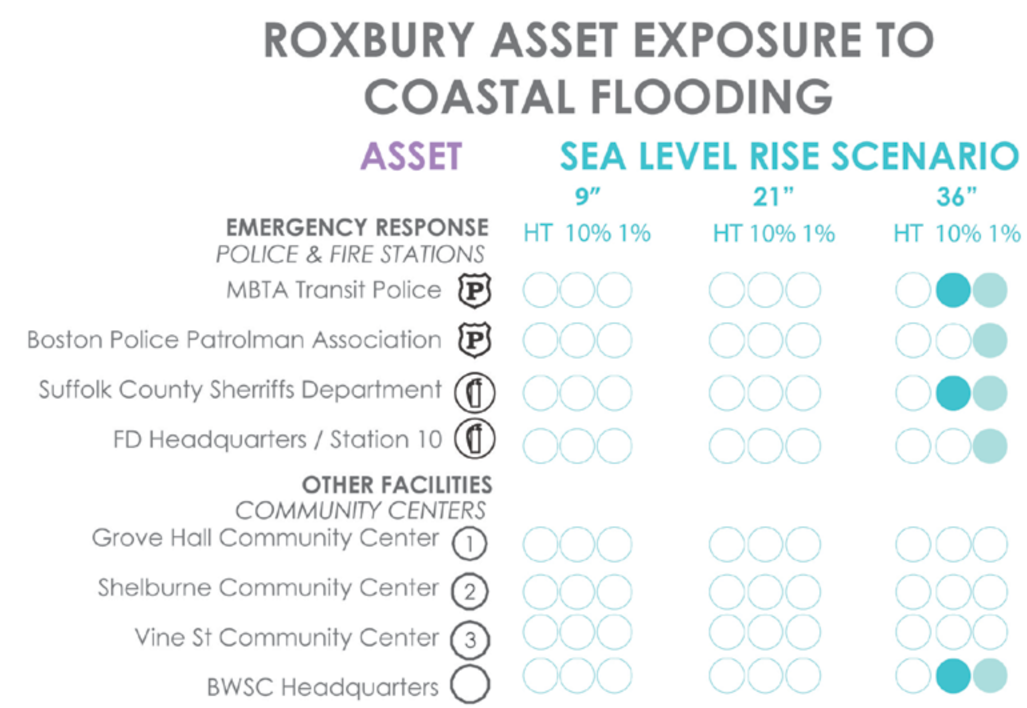
INFRASTRUCTURE

Damage to exposed roads and the MBTA Red Line could isolate Columbia Point from the rest of Dorchester, and impact transportation connections to North Quincy.

The Boston Water and Sewer Commission (BWSC) Headquarters, located in the northern portion of Roxbury, will be exposed to high-probability flooding later in the century (10 percent annual chance event). As a critical facility, BWSC Headquarters employs system redundancies. Notwithstanding backup power supply, loss of power to the structure would disable all computerized systems , including work order management, and major building functions such as vehicle fueling. Such functionality disruptions at the Headquarters building may result in delayed repair of BWSC assets throughout Greater Boston.

Facilities which support Roxbury's police and fire services are exposed to sea level rise and coastal storms.

In northern Roxbury, the Suffolk County Sheriff, MBTA Transit Police Headquarters, and two of three fire stations are exposed to the high-probability storms expected by later in the century (10 percent annual chance event).



EXPOSURE AND CONSEQUENCES

BUILDINGS AND ECONOMY

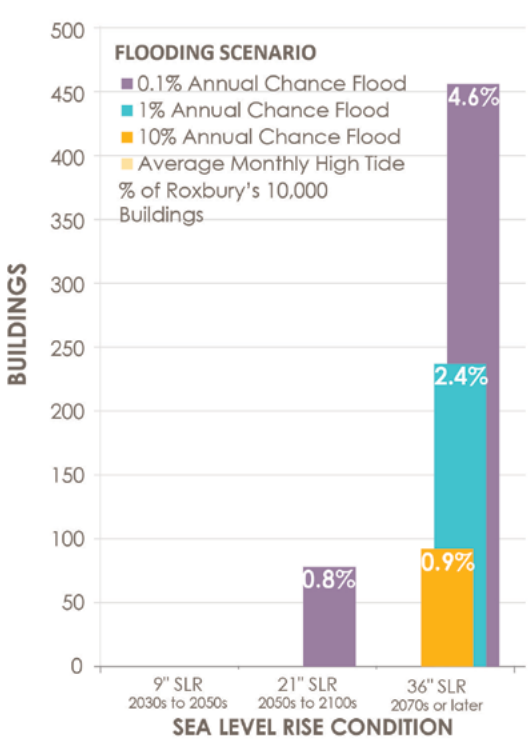
RISK TO BUILDINGS

Almost 80 structures in Roxbury are expected to be exposed to mid-century coastal flooding for the 0.1 percent annual chance event. This number increases to 450 buildings exposed to high-probability flooding later in the century (1 percent annual chance event). Of the buildings exposed later in the century, 40 percent of them are residential or mixed-use in nature, followed by commercial buildings (20 percent). Though these buildings are only a fraction of Roxbury's total building stock, the neighborhood can still expect over $30 million in annualized damage to buildings and other related costs with 36 inches of sea level rise.

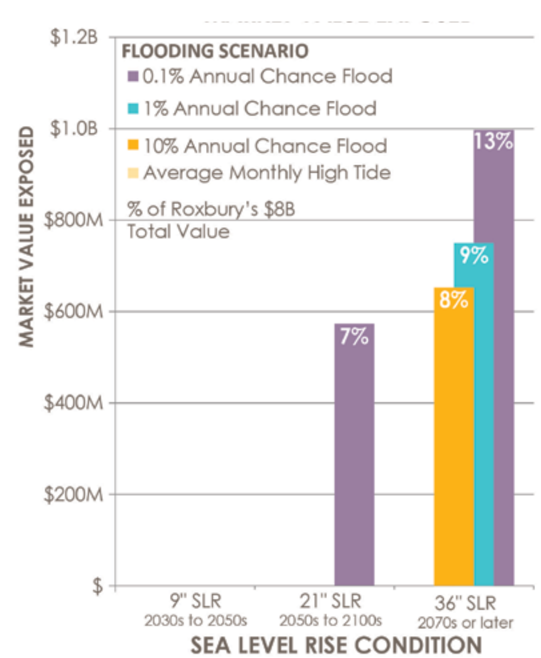
RISK TO THE ECONOMY

Dorchester provides Boston with close to 35,000 jobs and over $7 billion in annual output. Top employers in the community include public education, hospitals, and grocers, though no one industry seems to dominate. The economy is heavily service-oriented. As with other service-oriented neighborhood economies, restaurants are expected to be most heavily impacted in a flood event, particularly considering expected loss of employment. This is expected to be the case throughout the century. By late-century, coastal flood impacts to Dorchester are expected to result in 110 annualized jobs lost and about $15 million in annualized output loss to the current Boston economy. Restaurants are expected to comprise roughly 40 percent of job loss and 20 percent of output loss. Restaurants tend to employ low- to moderate-income personnel, and business interruption to such assets can exacerbate impacts to already vulnerable populations.

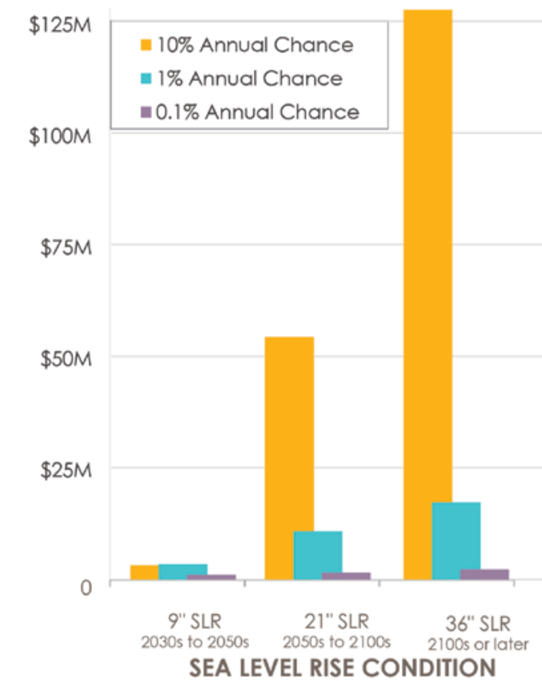
ROXBURY BUIILDINGS EXPOSURE



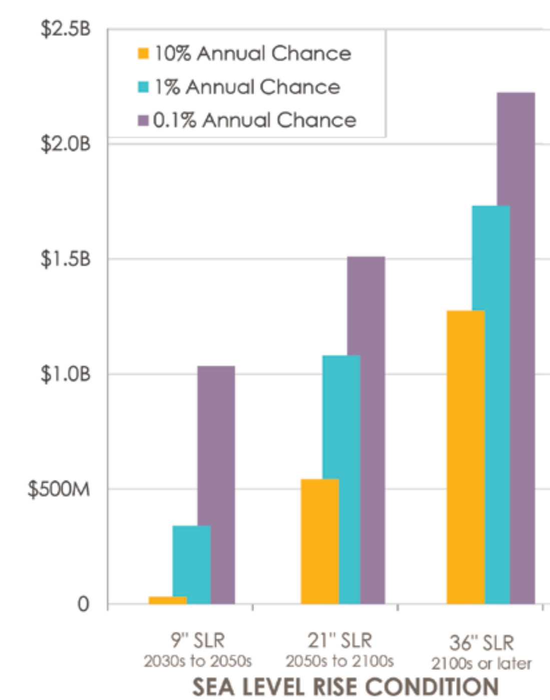
ROXBURY REAL ESTATE MARKET VALUE EXPOSURE



ROXBURY ANNUALIZED LOSSES



ROXBURY ECONOMIC LOSSES

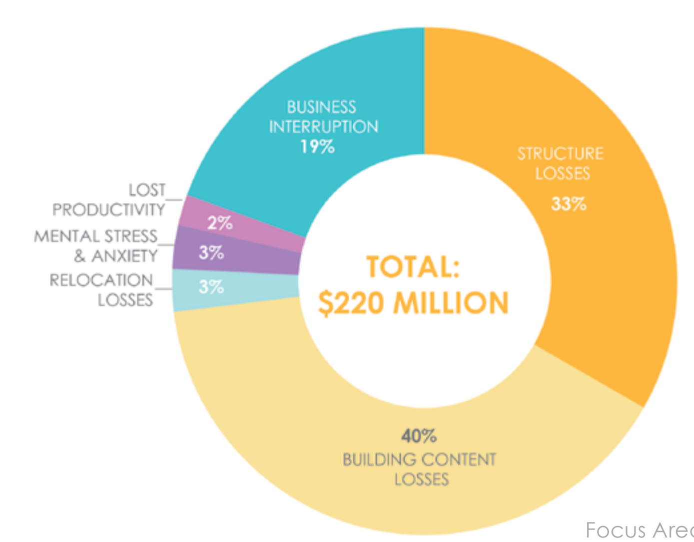


ECONOMIC RISK ASSUMPTIONS

Job and output loss includes direct, indirect, and induced consequences of flood impacts. Direct results are impacts felt within a neighborhood, while indirect and induced results are those expected to be felt throughout Suffolk County as a result of changes in spending patterns. Results for both job and output losses are the sum of annualized values for the four flood frequencies analyzed for each sea level rise scenario. This represents a lower-bound estimate for several reasons. First, not all probabilistic events are considered. Second, the analysis assumes that all impacted businesses eventually reopen, though FEMA estimates that almost 40 percent of small businesses—and up to 25 percent of all businesses—never reopen after experiencing flood impacts. Third, only building areas directly impacted by floodwater are assumed to experience business interruption. This does not consider interruptions of businesses due to loss of power or utility functions. Finally, the analysis only considers existing populations, businesses, and buildings and does not include projections for future growth. Refer to the Appendix for a more detailed explanation of the exposure and consequence analysis.

INDUSTRY	ANNUALIZED LOSS OF ECONOMIC OUTPUT
Restaurants	$442,000
Healthcare and medical services	$188,000
Real estate	$98,000
Other industries	$672,000
Total	**$1,400,000**

EAST BOSTON ANNUALIZED LOSSES
36 INCH SEA LEVEL RISE CONDITION



ROXBURY

APPLICATION OF RESILIENCE INITIATIVES

PROTECTED SHORES

PRIORITIZE AND STUDY THE FEASIBILITY OF DISTRICT-SCALE FLOOD PROTECTION

To reduce the risk of coastal flooding at major inundation points, the City should study the feasibility of constructing district-scale flood protection at the primary flood entry points for Roxbury (see Potential Flood Protection Locations below for a preliminary identification of locations and potential benefits). As described below, flood protection systems that would benefit Roxbury would likely be located outside of Roxbury, in South Boston, Dorchester, and by the New Charles River Dam.

These feasibility studies should feature engagement with local community stakeholders, coordination with infrastructure adaptation, and considerations of how flood protection would impact or be impacted by neighborhood character and growth. Examples of prioritization criteria include the timing of flood risk, consequences for people and economy, social equity, financial feasibility, and potential for additional benefits beyond flood risk reduction.

POTENTIAL DISTRICT-SCALE FLOOD PROTECTION LOCATIONS[2]

See the District-Scale Flood Protection Systems Overview section (p.330) for a citywide perspective on district-scale flood protection. District-scale flood protection is only one piece of a multilayered solution that includes prepared and connected communities, resilient infrastructure, and adapted buildings.

[2] These preliminary coastal flood protection concepts are based on a high-level analysis of existing topography, rights-of-way, and urban and environmental conditions. Important additional factors, including existing drainage systems, underground transportation and utility structures, soil conditions, zoning, as well as any potential external impacts as a result of the project have not been studied in detail. As described in Initiatives 5-2 and 5-3 (see pp. 106,110), detailed feasibility studies and appropriate public and stakeholder engagement are required in order to better understand the costs and benefits of flood protection in each location.

In the near term, coastal flood risk in Roxbury is minimal and likely does not require district-scale flood protection.

As soon as the 2050s, the northern edge of Roxbury will be exposed to flooding from Fort Point Channel and other inland flood pathways, so combined flood protection at multiple locations will be critical:

- At the **South Boston Waterfront,** addressing inland flood pathways originating from Fort Point Channel, Boston Harbor, and the Reserve Channel
- At **Dorchester Bay,** addressing inland flood pathways originating from the Old Harbor and Savin Hill Cove
- At the **New Charles River Dam,** addressing potential overtopping or flanking of the dam

SLR SCENARIO	DISTRICT SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD[3]
9" SLR (2030s–2050s)	None
21" SLR (2050s–2100s)	The South Boston Waterfront and Dorchester Bay locations combined
36" SLR (2070s or later)	The New Charles River Dam, South Boston Waterfront, and Dorchester Bay locations combined

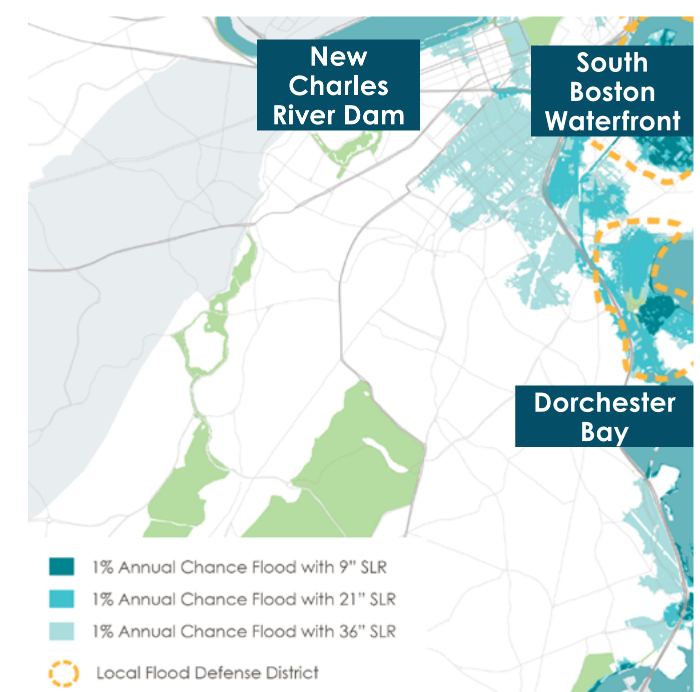
LOCATIONS

- **The South Boston Waterfront location,** described in the South Boston focus area (see p. 282), addresses flood entry points along the edge of the district.
- **The Dorchester Bay location,** described in the Dorchester focus area (see p.194), addresses flood pathways from the Old Harbor and Savin Hill Cove.
- **The New Charles River Dam location,** described in the Charles River and Downtown focus areas (see pp. 174, 216), addresses potential overtopping or flanking of the dam.

[3] Additional flood protection may be required for flood events more severe than the 1 percent annual chance flood. See Appendix for more detailed information on expected effectiveness of flood protection systems, including analysis of additional flood protection locations and flood frequencies.

DETAILED CONSIDERATIONS

- Flood protection at multiple locations likely required to accommodate later-century flood event scenarios: Late century, flood protection solutions at the South Boston Waterfront and Dorchester Bay may not be independently effective for the 1 percent annual chance event and events with lower probability of occurrence and may require an intervention at the New Charles River Dam to impede flooding from the Charles River. While investments at all three locations may be significant, losses avoided are expected to be substantial because an integrated system could protect Downtown, South Boston, Dorchester, the South End, Roxbury, and neighborhoods along the Charles River.



PREPARED & CONNECTED COMMUNITIES

CONDUCT AN OUTREACH CAMPAIGN TO PRIVATE FACILITIES THAT SERVE VULNERABLE POPULATIONS TO ENSURE THAT THEY ENGAGE IN EMERGENCY PREPAREDNESS AND ADAPTATION PLANNING

The City should conduct outreach to managers of facilities in Roxbury that serve significant concentrations of vulnerable populations and are not required to have operational preparedness and evacuation plans under current regulations. The City will inform these facilities about the need to prepare for climate change impacts, especially stormwater flooding and extreme heat in the near term. Targeted facilities will include affordable housing complexes, substance abuse treatment centers, daycare facilities, food pantries, small nonprofit offices, and others. Illustrative examples of the types of Roxbury facilities to which the City might conduct outreach include the American Red Cross/Boston Pantry, the Sojourner House Food Pantry, and Tartt's Day Care Center.[4]

EXPAND BOSTON'S SMALL BUSINESS PREPAREDNESS PROGRAM

The City should reach out to small businesses in Roxbury that are exposed to stormwater flooding in the near term to help them develop business continuity plans, evaluate insurance coverage needs, and identify low-cost physical adaptations. In particular, the City will reach out to businesses along Melnea Cass Boulevard, which experiences stormwater flooding impacts today.

UPDATE THE CITY'S HEAT EMERGENCY ACTION PLAN

The City should pilot components of its heat emergency plan in Roxbury, given the high concentration of socially vulnerable populations there. The City can partner with Renew Boston and the Boston Home Center's repair program to provide energy-efficient air conditioners for physically homebound people who cannot leave their homes without assistance. The City also can partner with Roxbury nonprofits to establish a network of neighborhood-level volunteers to check in on neighbors during heat events. In addition, the City can partner with community nonprofits and healthcare providers to register disabled residents who lack cooling capacity in their homes register for THE RIDE, if interested, in advance of heat events.

[4]The City did not review the extent of existing preparedness planning as part of this study.

RESILIENT INFRASTRUCTURE

ESTABLISH INFRASTRUCTURE COORDINATION COMMITTEE

In the near term, the City will support the MBTA in conducting a full asset-level vulnerability assessment of its system, including the Orange Line. Stormwater flooding is projected to impact bus routes on Massachusetts Avenue and Melnea Cass Boulevard and Orange Line rail lines between Tremont and Columbus Avenue.

PROVIDE GUIDANCE ON PRIORITY EVACUATION AND SERVICE ROAD INFRASTRUCTURE TO THE ICC

The Office of Emergency Management will work with the Boston Transportation Department, Department of Public Works, and Roxbury's private utilities to develop a list of critical roads to prioritize for adaptation, given that Roxbury's road infrastructure faces significant risk from stormwater flooding in all future conditions. Melnea Cass Boulevard is already impacted today under heavy rains.

CONDUCT FEASIBILITY STUDIES FOR COMMUNITY ENERGY SOLUTIONS

The 2016 Boston Community Energy Study identified several locations in Roxbury as potential locations for energy justice microgrids. This summer, the DOE Combined Heat and Power (CHP) Technical Assistance Partnerships analyzed municipal facilities and affordable housing in Roxbury, concluding that CHP is economically feasible. The City will work with the community to explore options for microgrids in this neighborhood. The Community Energy Study also found that Roxbury has high solar power generation potential relative to other Boston neighborhoods.

ADAPTED BUILDINGS

PROMOTE CLIMATE READINESS FOR PROJECTS IN THE DEVELOPMENT PIPELINE

Upon amending the zoning code to support climate readiness (see Initiative 9-2, p.135), the Boston Planning and Development Agency (BPDA) should immediately notify all developers with projects in the development pipeline in the future floodplain that they may alter their plans in a manner consistent with the zoning amendments (e.g., elevating their first-floor ceilings without violating building height limits), without needing to restart the BPDA permitting process. Currently, 31 residential buildings are under construction or permitted in Roxbury, representing 434 additional housing units. To the extent that these buildings are at risk for coastal flooding, the City will reach out to property owners so that they can make necessary adjustments without re-permitting.

INCORPORATE FUTURE CLIMATE CONDITIONS INTO AREA PLANS AND ZONING AMENDMENTS

The Boston Planning and Development Agency should incorporate future climate considerations (long-term projections for extreme heat, stormwater flooding, and coastal and riverine flooding) into major planning efforts in Roxbury.

ESTABLISH A CLIMATE READY BUILDINGS EDUCATION PROGRAM FOR PROPERTY OWNERS, SUPPORTED BY A RESILIENCE AUDIT PROGRAM

The City should develop and run a Climate Ready Buildings Education Program and a resilience audit program to inform property owners about their current and future climate risks and actions they can undertake to address these risks. A resilience audit should help property owners identify cost-effective, building-specific improvements to reduce flood risk, such as backflow preventers, elevation of critical equipment, and deployable flood barriers; promote interventions that address stormwater runoff or the urban heat island effect, such as green roofs or “cool roofs” that reflect heat; and encourage owners to develop operational preparedness plans and secure appropriate insurance coverage. The resilience audit program should include a combination of mandatory and voluntary, market-based and subsidized elements.

PREPARE MUNICIPAL FACILITIES FOR CLIMATE CHANGE

The City should develop and run a Climate Ready Buildings Education Program and a resilience audit program to inform property owners about their current and future climate risks and actions they can undertake to address these risks. A resilience audit should help property owners identify cost-effective, building-specific improvements to reduce flood risk, such as backflow preventers, elevation of critical equipment, and deployable flood barriers; promote interventions that address stormwater runoff or the urban heat island effect, such as green roofs or “cool roofs” that reflect heat; and encourage owners to develop operational preparedness plans and secure appropriate insurance coverage. The resilience audit program should include a combination of mandatory and voluntary, market-based and subsidized elements.

South Boston

Of all Boston focus areas, South Boston consistently faces the greatest or near-greatest exposure and potential losses to coastal flooding across all sea level rise conditions and flood events.

South Boston is a peninsula located to the southeast of Downtown Boston, bounded by Fort Point Channel and Dorchester Bay. The community includes the South Boston Waterfront to the north, also referred to as the Seaport or the Innovation District, and the Fort Point Channel Landmark District and a historic residential district to the south.

High ground within South Boston, such as Telegraph Hill, illustrates the original landforms of Boston waterfronts before land filling began in the early 1800s; significant portions of the community are filled-in mudflats. South Boston was annexed to the city in 1804 to accommodate Boston's need for additional residential and commercial land. The Old Colony Railroad opened in 1845.

In recent years, South Boston has experienced rapid transformation as the result of a development boom and significant investment. From 2010–2013, the South Boston Waterfront was the fastest-growing urban area in the commonwealth, adding approximately ten million square feet of development. The waterfront has become a hub for recreation and culture, with the expansion or opening of numerous attractions, including the Boston Convention and Exhibition Center (opened 2004), Institute of Contemporary Art (opened 2006), and Boston Children's Museum (renovated 2007), among others. The South Boston Waterfront is expected to increasingly become a mixed-use neighborhood with a large residential population. Seaport Square and Fan Pier are examples of large mixed-use development projects. The area still maintains marine industrial uses to the northeast, tied to the Port of Boston, the Raymond L. Flynn Industrial Park (former Boston Marine Industrial Park), and the Fish Pier.

The historic residential neighborhood to the south has experienced significant real estate appreciation, with an influx of young professionals. The area's commercial district is centered around East and West Broadway. South Boston contains several large Boston Housing Authority (BHA) housing developments, including West Broadway, West Ninth Street, Old Colony, and Foley.

Due to the rapid changes occurring in this area, the City recently has begun the planning process for several key projects focused on transportation and public realm improvements. Examples include the South Boston Waterfront Plan, the 100 Acres Master Plan process for the areas around the Procter & Gamble Gillette plant, and the Dorchester Avenue Corridor Plan, which is focused on supporting a diversity of mixed uses between Andrew and Broadway Red Line MBTA Stations.

Image courtesy of Sasaki

FLOOD PROGRESSION

DEFINITIONS

Near term: Beginning 2030s, assumes 9 inches of sea level rise

Midterm: Beginning 2050s, assumes 21 inches of sea level rise

Long term: Beginning 2070s or later, assumes 36 inches of sea level rise

Exposure: Can refer to people, buildings, infrastructure, and other resources within areas likely to experience hazard impacts. Does not consider conditions that may prevent or limit impacts.

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Consequence: Illustrates to what extent people or assets can be expected to be affected by a hazard, as a result of vulnerability and exposure. Consequences can often be communicated in terms of economic losses.

Annualized losses: The sum of the probability-weighted losses for all four flood frequencies analyzed for each sea level rise scenario. Probability-weighted losses are the losses for a single event times the probability of that event occurring in a given year.

*For a full list of definitions, refer to the Glossary in the Appendix.

South Boston is exposed to climate change impacts including heat, increased precipitation and stormwater flooding, and sea level rise and coastal and riverine flooding. Exposure to heat and stormwater flooding are addressed in the Citywide Vulnerability Assessment (see p.12), while exposure and consequences to coastal and riverine flood risk are further discussed in this section.

In the near term, a significant portion of the South Boston Waterfront is exposed to high-probability coastal storms (10 percent annual chance events), particularly near Fort Point Channel and to the north along Boston Harbor.

South Boston's exposure will increase significantly over the course of the century, with a substantial portion of the South Boston Waterfront exposed to both chronic high-tide flooding and more severe flooding during coastal storms. Over the century, flooding from Fort Point Channel and Dorchester Bay will increase, exposing residential areas.

9 INCHES SEA LEVEL RISE

21 INCHES SEA LEVEL RISE

36 INCHES SEA LEVEL RISE

LEGEND

- Average Monthly High Tide
- 10% Annual Chance Storm
- 1% Annual Chance Storm
- Parks
- Roads
- Major Roads
- Major Tunnels
- Evacuation Route
- Evacuation Route Tunnels
- MBTA Blue Line
- MBTA Silver Line Station
- MBTA Station
- I-90 On/Off Ramp Tunnel Entrances
- I-90 Tunnel Entrances
- Frontage Road BTD/PWD
- City of Boston Police
- State Police Station E-4, Tunnels
- State Police, Massachusetts Turnpike
- BPD Harbor Patrol
- College or University
- School
- Police Station
- Fire Station
- Electric Substation or Pump Station
- Healthcare Center
- 1 Condon Community Center (BCYF)
- 2 Curley Community Center (BCYF)
- 3 EMS Station 6 (A6)
- 4 EMS Harbor Unit
- 5 Tynan Community Center (BCYF)
- Senior Housing
- Longterm Care Facility
- BHA Public Housing

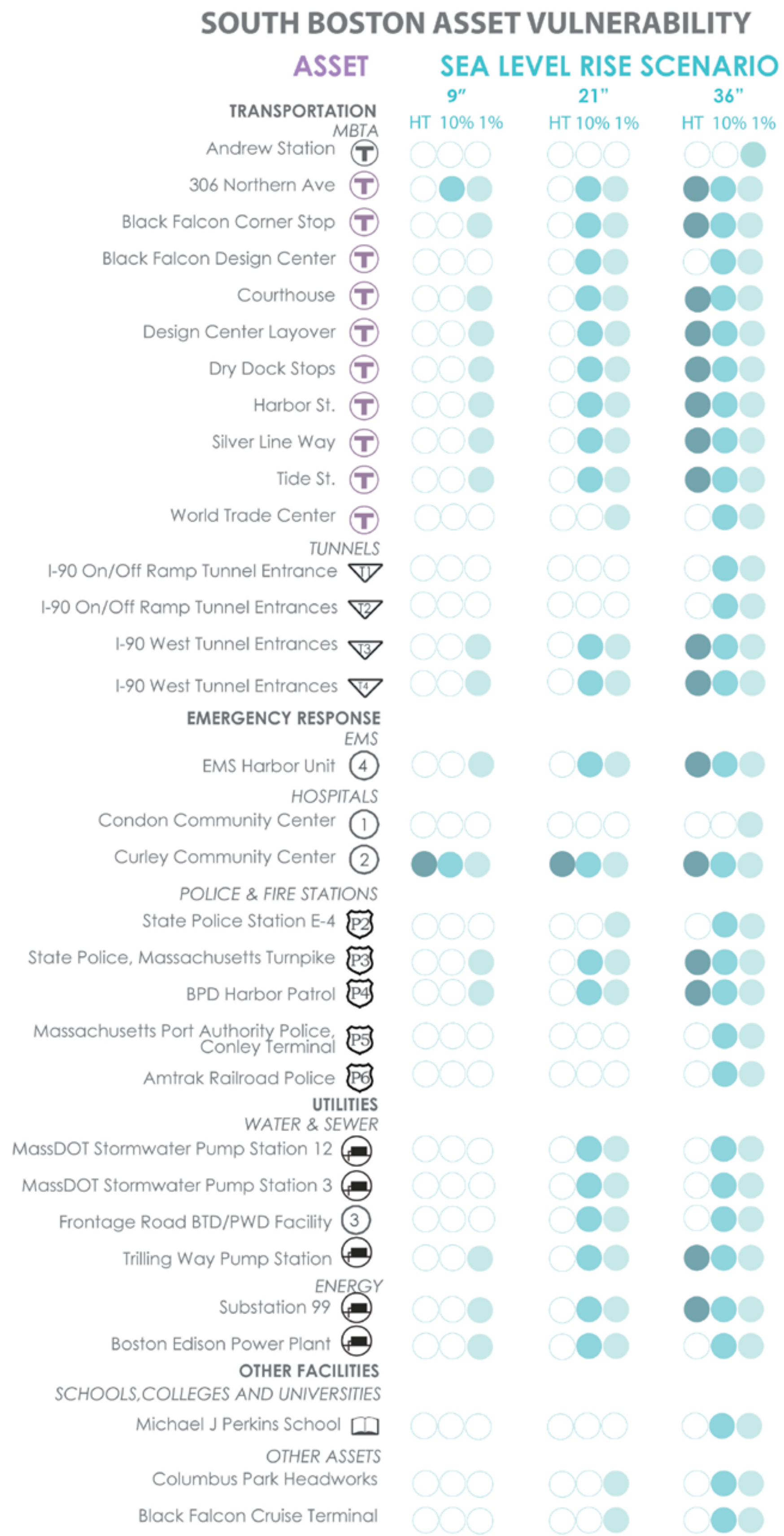
South Boston is the most-exposed[1] neighborhood in Boston, with nearly 25 percent of its land area exposed under 9 inches of sea level rise, 50 percent under 21 inches, and 60 percent under 36 inches at the 1 percent annual chance event. Nearly 20 percent of the neighborhood's land area will be exposed to high tides with 36 inches of sea level rise.

Resilience planning requires consideration of the South Boston Waterfront's long, low-lying waterfront edges and flood pathways through Fort Point Channel and Joseph Moakley Park, which create challenges for local flood defenses.

In the first half of the century, expected exposure to coastal flooding is primarily due to the low waterfront edges along Fort Point Channel, Boston Harbor, and the Reserved Channel. During this time, nearly a quarter of South Boston's land area will be exposed to 1 percent annual chance flood events, with some heavily developed areas along the Fort Point Channel also exposed to higher probability events (10 percent annual chance).

In the second half of the century, flood exposure will increase due to flood entry points at Joseph Moakley Park in the southeast and along the Fort Point Channel that impact inland, largely residential areas in South Boston. With 21 inches of sea level rise, much of the land area north of West First Street and East First Street will be exposed to 10 percent annual chance floods. **The probability of flooding across the neighborhood will increase by an order of magnitude by the second half of the century.**

Toward the end of the century, considerable portions of the South Boston Waterfront will be exposed to flooding from high tide, and many residential areas are exposed to 10 percent annual chance



[1]Based on the percentage of the land area in the neighborhood exposed to coastal flooding

EXPOSURE

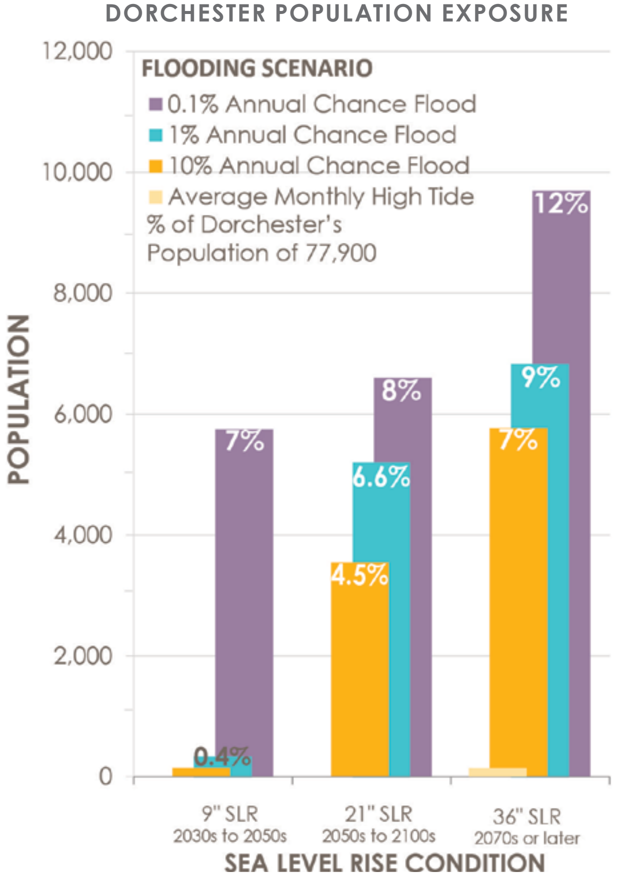
POPULATION & INFRASTRUCTURE

POPULATION AND SOCIAL VULNERABILITY

South Boston is currently home to over 31,000 people. Overall, South Boston has lower numbers and percentages of socially vulnerable groups than other Boston neighborhoods. The neighborhood is less racially diverse than neighboring Dorchester and the South End, with people of color comprising just 22 percent of its population (compared to 52 percent citywide). Twenty-six percent of South Boston residents are those with low to no income (compared to 28 percent citywide). In contrast to other Boston neighborhoods that demonstrate widespread social vulnerability, South Boston has vulnerable groups in concentrated pockets in and around public housing projects in the area.

In both the near and long term, South Boston can expect negative impacts to its population from widespread overland flooding. This flooding is expected to displace residents, interrupt electrical and water service of flooded buildings with mechanical, electrical, and plumbing assets in the basement or first floor, and result in employment and sales losses, most significantly to industries that support low- to moderate-income populations (see Risk to the Economy, below). In the near term, roughly 100 people currently live in areas expected to be flooded by high tides, and over 1,600 people currently live in areas expected to be flooded by high-probability flood events (10 percent annual chance event). In a significant expansion of risk, over 2,200 residents currently live in areas expected to be flooded by high tides toward the end of the century. This represents an increase of roughly 22 times from the near term. With 36 inches of sea level rise, between 10,000 and 12,000 people could face displacement under a 1 percent annual chance event.

DORCHESTER POPULATION EXPOSURE



In the near term, one of South Boston's emergency shelters (the Curley Center) is expected to be exposed to high-tide flooding. If the Curley Center is compromised, South Boston will lose a quarter of its sheltering capacity (62 people). Further, South Boston's current sheltering capacity may not be adequate for the scale of flooding expected toward the end of the century, when roughly 1,200 people are expected to require public shelter during a 1 percent annual chance flood event.

In the second half of the century, BHA's Mary Ellen McCormack Development, the first and still largest public housing development in New England with 1,016 units in 22 buildings, will be exposed to relatively low-probability events (1 percent annual chance). As soon as the 2070s, the development will be exposed to more frequent (10 percent annual chance) floods.

INFRASTRUCTURE EXPOSURE[2]

South Boston has important transportation assets located in the future floodplain, including I-90 (Massachusetts Turnpike), the Ted Williams Tunnel entrances and exits, the South Boston Bypass/Massport Haul Road, and William J. Day Boulevard.

In the near term, I-90 and the Ted Williams Tunnel are expected to be exposed to low-probability coastal flooding (1 percent annual chance). The Ted Williams Tunnel links South Boston to East Boston (Logan International Airport) by carrying I-90 under the Boston Harbor, allowing direct access to Route 1A in East Boston. Congress Street and Summer Street, which connect South Boston to Downtown, have portions exposed to a high-probability coastal flood event in the near term. As soon as the 2050s, South Boston's remaining evacuation routes, including the South Boston Bypass, (linking the South Boston waterfront to South Bay), Dorchester Avenue, I-93, and William J. Day Boulevard (along the southeastern edge of South Boston) will all be exposed to low-frequency storm events (1 percent annual chance), in addition to many local roads, such as Old Colony Avenue and streets around Joseph Moakley Park. MassDOT's Stormwater Pump Station 3, which protects the South Boston Bypass, is also exposed to high-probability storm events expected as soon as the 2050s.

Flooding of evacuation routes and local roads could affect safe evacuation for residents and potentially isolate South Boston during a storm event. With major roadways blocked by floodwaters within and along the outskirts of the neighborhood, it may be difficult to bring in resources by automobile during an emergency situation. In addition, road closures and flooded tunnels may have an impact on Silver Line operations; eight Silver Line stations are exposed to lower-probability events in the near term (1 percent chance event) and may be exposed to high tides later in the century. Rail options in South Boston are also limited by flood exposure; the Franklin and Greenbush commuter rail lines that run through South Boston will be exposed to low-probability flooding in the second half of the century, and the MBTA's Red Line may experience difficulty in maintaining operations at the Andrew Station later in the century during the 1 percent annual chance coastal flood event.

Impacts to transportation infrastructure and services in South Boston could have ripple effects on other neighborhoods—for example, by preventing East Boston residents from traveling down I-90. Tourism may also be affected if conventioneers or cruise travelers are unable to access the Boston Convention and Exhibition Center or the Black Falcon Cruise Terminal. The Black Falcon Cruise Terminal itself may experience impacts in lower probability events as soon as the 2050s (1 percent annual chance).

[2]This evaluation is preliminary. Site-specific analysis and detailed cascading impact mapping is necessary to fully understand facility-level and neighborhood vulnerabilities, as well as the extent of potential consequences.

Widett Circle, an area that Boston seeks to redevelop, will be exposed to high-probability flood impacts expected from mid-century storm events.

Widett Circle has been a focus of several redevelopment initiatives proposed by the MBTA and the BRA. Though the site is no longer the primary recommended location of a train yard to accommodate South Station expansions, redevelopment of the area must consider sea level rise and coastal flood impacts to ensure that investments are protected in the long term.

Several power assets in South Boston are expected to be exposed under mid- to late- century sea level rise and coastal storm conditions, including four existing substations and a cogeneration facility.

Eversource Energy has constructed a new substation in the South Boston Waterfront to relieve the strain imposed by rapid waterfront development on power and electric systems in the area. Though Substation 99 is expected to be exposed to low-probability flooding in the near term (1 percent annual chance event), it sits on a 15-foot-high elevated steel platform with reinforced cast-in-place concrete at its base. Sitting almost 26 feet above current mean sea level, this substation is expected to withstand storm surge and flood scenarios throughout this century.

In addition, the former Boston Edison power plant at the corner of Summer and First Streets, near the Reserved Channel, will be exposed to flooding from high-probability storm events in the mid- to late century. While the plant is no longer operational, and the 18-acre site is being offered for redevelopment following environmental remediation, any remaining contamination at the site could present a threat to public health and safety with flooding.

South Boston's sanitary sewage system is exposed to coastal flooding and sea level rise in the near term. Planned improvements to the sanitary sewage system could mitigate service interruption due to expected flooding.

South Boston's sanitary sewage system is largely dependent upon two pump stations, one of which will be exposed to a 1 percent annual chance flood event in the near term and a 10 percent annual chance flood event by the second half of the century. While the sewage system and pumps have the capacity to handle large flows in dry weather conditions, overflows are likely during storm events, causing sewage backup into streets, homes, and businesses. Since roads surrounding the pump station are also expected to flood, repair crews might not be able to remedy loss of function right away if the pump station were to fail. A redundant force main is being constructed in order to limit service disruption; these improvements may also mitigate flood impacts.[3]

The Columbus Park Headworks facility, which will be exposed to low-probability storms in the mid-century, screens wastewater for inorganics and removes sticks, stones, grit, and sand to protect and reduce wear on the Deer Island Wastewater Treatment Plant. The facility currently services a tributary area of approximately 13 miles.[4]

[3]A detailed analysis is needed to understand coastal storm impacts to South Boston's sanitary sewage system.

[4]Impacts to Boston's wastewater infrastructure due to flood impacts at this facility require detailed analysis.

Local access roads to the facility are exposed to mid-century low-probability flooding as well, which may inhibit repair crews from addressing potential facility damage.

South Boston is expected to experience reduced emergency response capacity as a result of sea level rise.

Of South Boston's two Emergency Medical Services (EMS) facilities, the EMS Harbor Unit is expected to be exposed to low-probability flooding in the near term (1 percent annual chance). Furthermore, five law enforcement facilities are expected be located within the 1 percent annual chance floodplain in the late century, potentially reducing emergency response capacity within South Boston. South Boston may also become islanded under a late-century storm event, which would limit the ability of outside emergency response vehicles to travel into South Boston. Delayed or reduced emergency response would exacerbate any potential flood impacts.

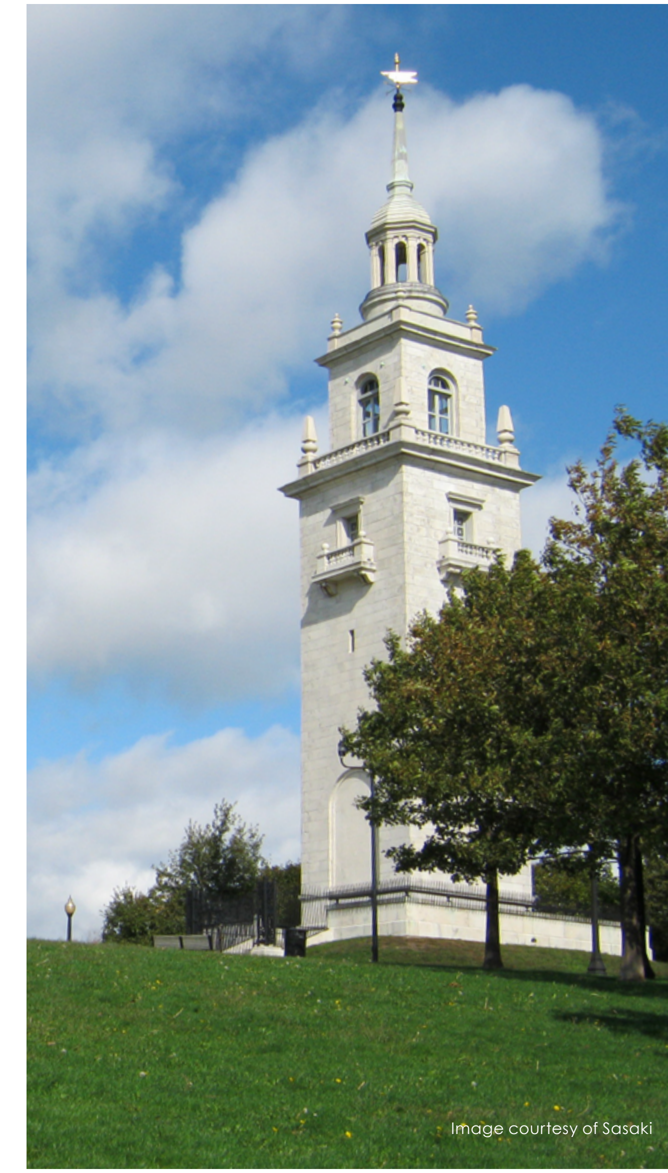


Image courtesy of Sasaki

EXPOSURE AND CONSEQUENCES
BUILDINGS AND ECONOMY

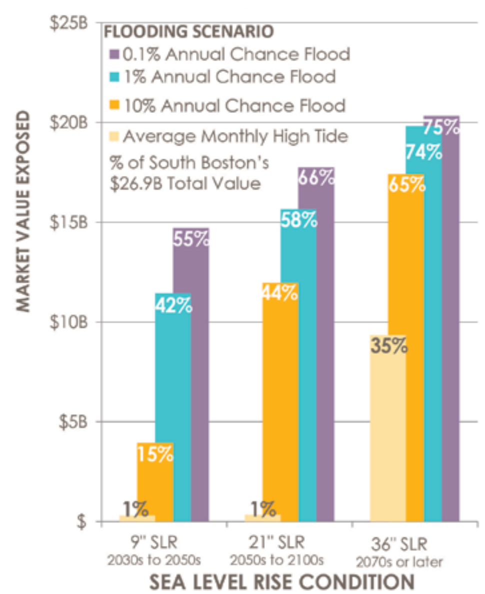
RISK TO BUILDINGS

South Boston comprises close to 60 percent of Boston's total real estate market value exposed to coastal flooding associated with low-probability events (1 percent annual chance) in the near term. South Boston is second only to Downtown with total real estate market value expected to be exposed to flooding during high tides in the near term. In the late century, the community will continue to have the largest share (25 percent) of Boston's total real estate market value exposed.

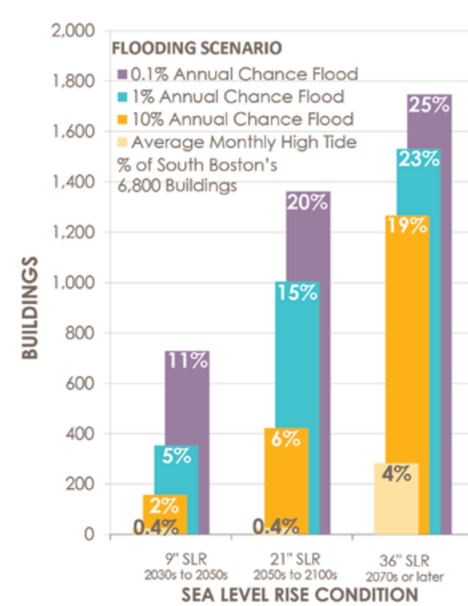
Perceived or actual flood risk can affect the value of existing assets as well as insurance and operating costs and the feasibility of future development. This is particularly the case for areas exposed to frequent flood impacts, such as those associated with high tides or high-probability coastal flood events (10 percent annual chance).

South Boston represents almost half of the city's expected losses to buildings in the near term and will maintain its position as the single most-vulnerable neighborhood, as measured by projected damage costs through the end of the century.

SOUTH BOSTON REAL ESTATE MARKET VALUE EXPOSURE



SOUTH BOSTON BUILDING EXPOSURE



While exposure and expected damage costs in South Boston are the most dramatic across the city, these losses are limited to relatively few, very large structures when compared to other relatively high expected loss neighborhoods.

Compared to other neighborhoods that occupy large shares of Boston's total expected losses, South Boston has a comparatively small number of buildings exposed to flooding across all coastal storm event scenarios. For example, East Boston has roughly three times as many buildings exposed to low-probability events in the near term as South Boston and ten times as many buildings later in the century. South Boston has a relatively high proportion of large, high-rise buildings exposed, which are expected to experience greater losses than buildings of low and medium height.

While high-rise buildings[5] occupy close to 10 percent of the building footprints within South Boston, they represent close to 15 percent of grade-level exposure within this neighborhood. (In East Boston, high-rise structures occupy less than 1 percent of the current building stock and just over 1 percent of grade-level exposure.) Though South Boston has a smaller number of buildings exposed to flooding under coastal storm events, it has more buildings and grade-level square footage exposed to high-tide flood events in the near term than in any other neighborhood, except Downtown. As a result, flood-related initiatives in South Boston, in the near term, might effectively focus on building-specific retrofits, though area-wide measures will be necessary over the long term to address high-tide flooding.

[5]High-rise buildings are defined for the purposes of this study as structures with greater than ten floors.

RISK TO THE ECONOMY

As of 2014, industries in South Boston contributed more than $20 billion in annual output (sales and revenues) to Boston's economy. Legal, financial, real estate, and insurance industries made up more than half of that value and close to half of the neighborhood's 78,000 jobs.

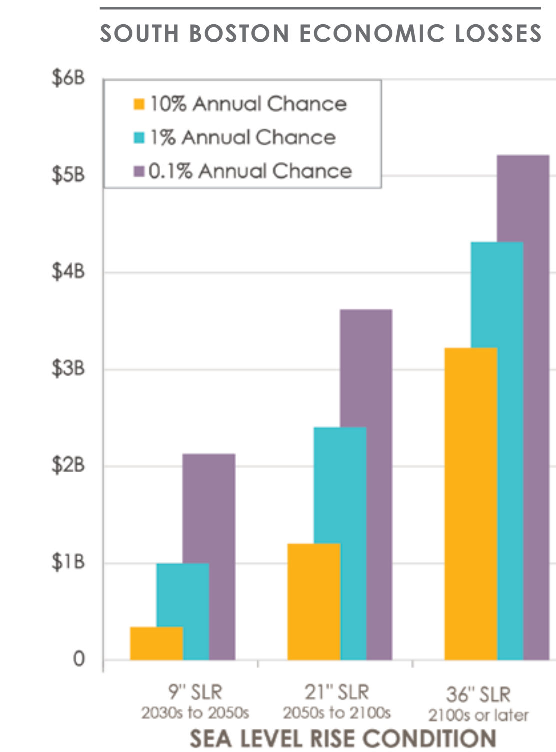
As soon as the 2070s, based on preliminary and conservative-modeled[6] evaluations, Boston could face close to $80 million in annualized lost output and close to 600 annualized lost jobs due to expected flood damage to structures in South Boston.[7] This estimate includes interruption from businesses directly exposed to flood impacts, as well as the reverberations that impact may have throughout Suffolk County's economy.[8] Except for the real estate industry, South Boston's other top-producing industries—legal, financial, and insurance industries—are considered resilient industries. These industries often maintain secure data redundancies and are usually able to operate remotely or relocate operations quickly.

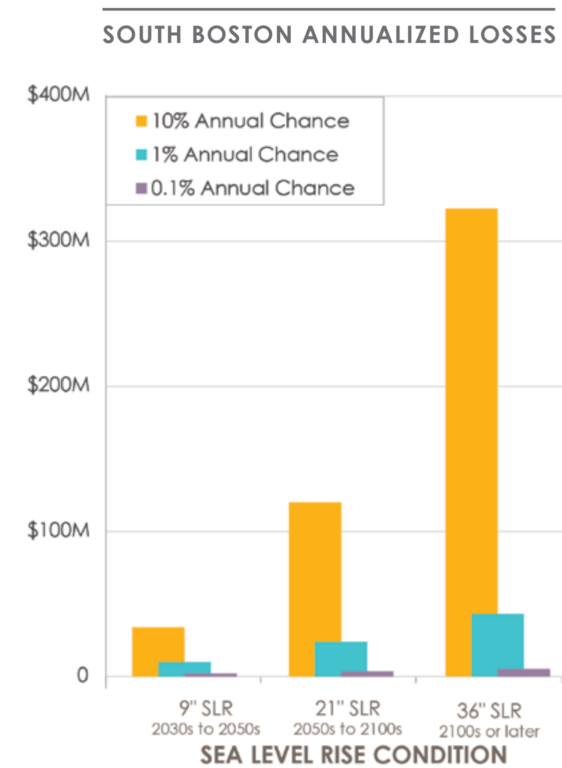
As in other neighborhoods, restaurants and retail are hit hard by flood impacts, representing over 30 percent of lost economic output and 50 percent of lost jobs from expected future flood conditions in the near term and later this century. Restaurants and retail establishments are often small businesses, and tend to employ low- to moderate-income personnel, which makes them important to considering impacts to socially vulnerable populations.

ECONOMIC RISK ASSUMPTIONS

Job and output loss includes direct, indirect, and induced consequences of flood impacts. Direct results are impacts felt within a neighborhood, while indirect and induced results are those expected to be felt throughout Suffolk County as a result of changes in spending patterns. Results for both job and output losses are the sum of annualized values for the four flood frequencies analyzed for each sea level rise scenario. This represents a lower-bound estimate for several reasons. First, not all probabilistic events are considered. Second, the analysis assumes that all impacted businesses eventually reopen, though FEMA estimates that almost 40 percent of small businesses—and up to 25 percent of all businesses—never reopen after experiencing flood impacts. Third, only building areas directly impacted by floodwater are assumed to experience business interruption. This does not consider interruptions of businesses due to loss of power or utility functions. Finally, the analysis only considers existing populations, businesses, and buildings and does not include projections for future growth. Refer to the Appendix for a more detailed explanation of the exposure and consequence analysis.

INDUSTRY	ANNUALIZED LOSS OF ECONOMIC OUTPUT
Restaurants	$150,000,000
Retail	$9,700,000
Real estate	$4,000,000
Insurance and legal services	$5,900,000
All remaining industries	$44,500,000
Total	**$78,900,000**





Despite occupying a relatively small share of the South Boston economy and employment, restaurant and retail industries could be hardest hit by flood impacts in the near and long term. These industries are sensitive to residential and business activity within an area and must be local to operate.

South Boston's top-producing industries are considered relatively resilient to disasters, as they are generally expected to have built-in system redundancies, data storage, and the capability to operate remotely.

[6]Economic loss calculations consider only impacts to floors expected to flood, only consider potential losses within the City (as opposed to regional or national losses), and assume all businesses eventually reopen. Please see the Appendix for a full list of assumptions.

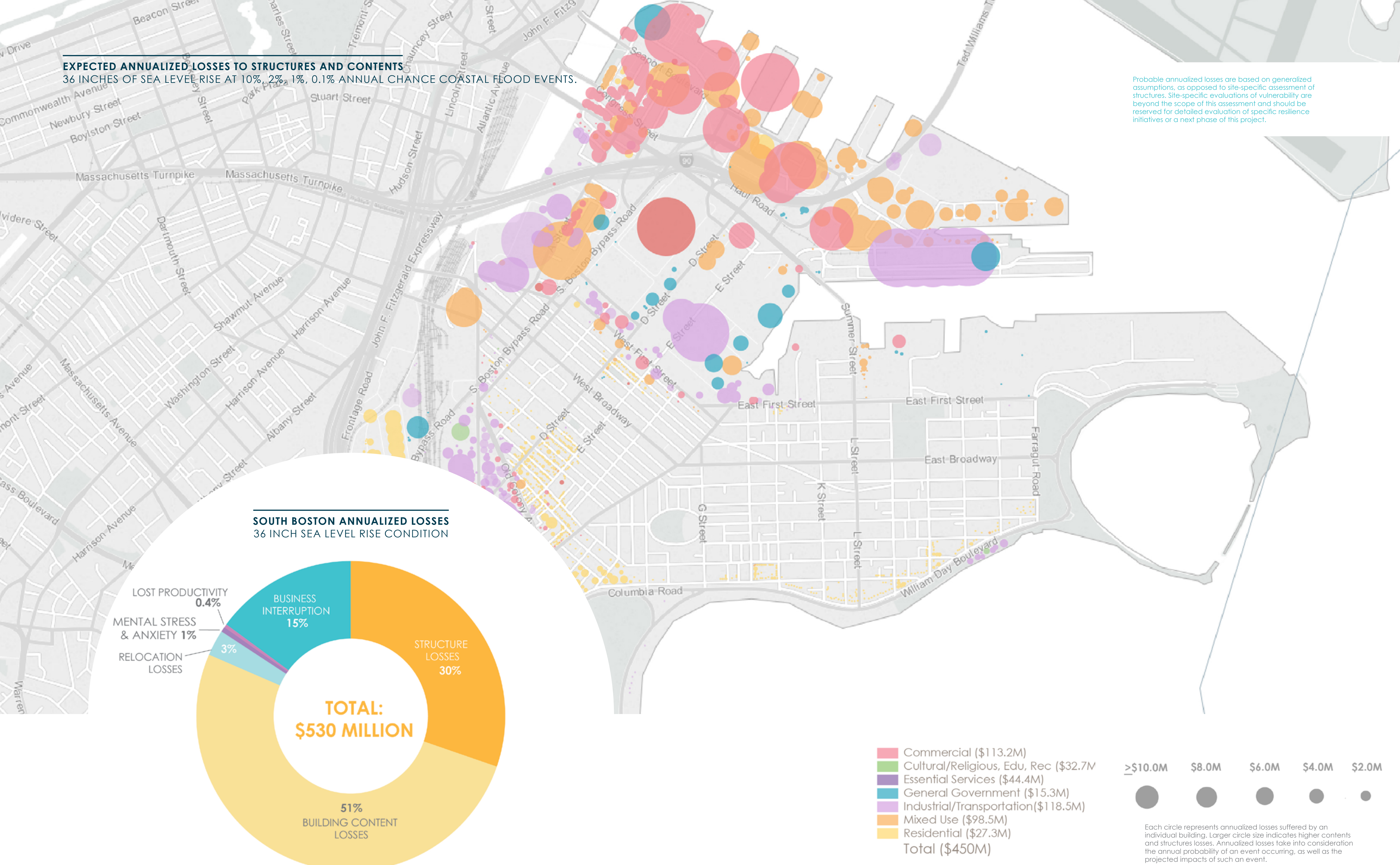
[7]Expected flood damages are calculated for the 10%, 2%, 1%, and 0.1% annual chance flood events only.

[8]Losses to particular industries are based on current development and economic activity in the area, and considering that South Boston is in a period of intense growth, may differ as development continues.

EXPECTED ANNUALIZED LOSSES TO STRUCTURES AND CONTENTS
36 INCHES OF SEA LEVEL RISE AT 10%, 2%, 1%, 0.1% ANNUAL CHANCE COASTAL FLOOD EVENTS.

Probable annualized losses are based on generalized assumptions, as opposed to site-specific assessment of structures. Site-specific evaluations of vulnerability are beyond the scope of this assessment and should be reserved for detailed evaluation of specific resilience initiatives or a next phase of this project.

SOUTH BOSTON ANNUALIZED LOSSES
36 INCH SEA LEVEL RISE CONDITION



- Commercial ($113.2M)
- Cultural/Religious, Edu, Rec ($32.7M
- Essential Services ($44.4M)
- General Government ($15.3M)
- Industrial/Transportation($118.5M)
- Mixed Use ($98.5M)
- Residential ($27.3M)

Total ($450M)

>$10.0M | $8.0M | $6.0M | $4.0M | $2.0M

Each circle represents annualized losses suffered by an individual building. Larger circle size indicates higher contents and structures losses. Annualized losses take into consideration the annual probability of an event occurring, as well as the projected impacts of such an event.

SOUTH BOSTON
APPLICATION OF RESILIENCE INITIATIVES

PROTECTED SHORES

DEVELOP LOCAL CLIMATE RESILIENCE PLANS TO SUPPORT DISTRICT-SCALE CLIMATE ADAPTATION

The City should develop a local climate resilience plan for South Boston to support district-scale climate adaptation. The plan should include the following:

- Community engagement through a local climate resilience committee, leveraging existing local organizations and efforts.
- Land use planning for future flood protection systems, including Flood Protection Overlay Districts in strategically important "flood breach points" identified below (see Potential Flood Protection Locations).
- Flood protection feasibility studies, evaluating district-scale flood protection, including at locations identified below (see Potential Flood Protection Locations).
- Infrastructure adaptation planning through the Infrastructure Coordination Committee. For South Boston, the Massachusetts Port Authority (Massport) is a key partner because they control significant land and assets. Massport is currently working with their tenants in South Boston to do operational preparedness planning.
- Coordination with other plans, including Imagine Boston 2030, GoBoston 2030, Special Planning Areas, and any updates to the South Boston Municipal Harbor Plan.
- Development of financing strategies and governance structures to support district-scale adaptation.

ESTABLISH FLOOD PROTECTION OVERLAY DISTRICTS AND REQUIRE POTENTIAL INTEGRATION WITH FLOOD PROTECTION

The Boston Planning and Development Agency (BPDA) should petition the Boston Zoning Commission to create new Flood Protection Overlay Districts in areas that are strategically important for potential future flood protection infrastructure (see Potential Flood Protection Locations below). Within a Flood Protection Overlay District, a developer would be required to submit a study of how a proposed project could be integrated into a future flood protection system; options may include raising and reinforcing the development site or providing room for a future easement across the site.

PRIORITIZE AND STUDY THE FEASIBILITY OF DISTRICT-SCALE FLOOD PROTECTION

To reduce the risk of coastal flooding at major inundation points, the City should study the feasibility of constructing district-scale flood protection at the primary flood entry points in South Boston (see Potential Flood Protection Locations below for a preliminary identification of locations and potential benefits).

These feasibility studies should take place in the context of local climate resilience plans, featuring engagement with local community stakeholders, coordination with infrastructure adaptation, and considerations of how flood protection would impact or be impacted by neighborhood character and growth. Examples of prioritization criteria include the timing of flood risk, consequences for people and economy, social equity, financial feasibility, and potential for additional benefits beyond flood risk reduction.

POTENTIAL DISTRICT-SCALE FLOOD PROTECTION LOCATIONS[9]

See the District-Scale Flood Protection Systems Overview section (p. 330) for a citywide perspective on district-scale flood protection. District-scale flood protection is only one piece of a multilayered solution that includes prepared and connected communities, resilient infrastructure, and adapted buildings.

Because the entire South Boston Waterfront is low lying, without high ground for a flood protection system to tie into, preventing inundation in this area is particularly challenging.

In the near term, district-scale flood protection is critical to address flood entry points around the entire edge of the **South Boston Waterfront**, from Fort Point Channel to Boston Harbor and the Reserve Channel.

To prevent inundation from inland flood pathways, flood protection for the South Boston Waterfront will need to be combined with the following:

- Protection from flood pathways from **Dorchester Bay** expected during very low-probability events in the near term and high-probability events expected by the 2050s
- Protection at the **New Charles River Dam,** addressing potential overtopping or flanking of the dam expected for the 1 percent annual chance event later in the century

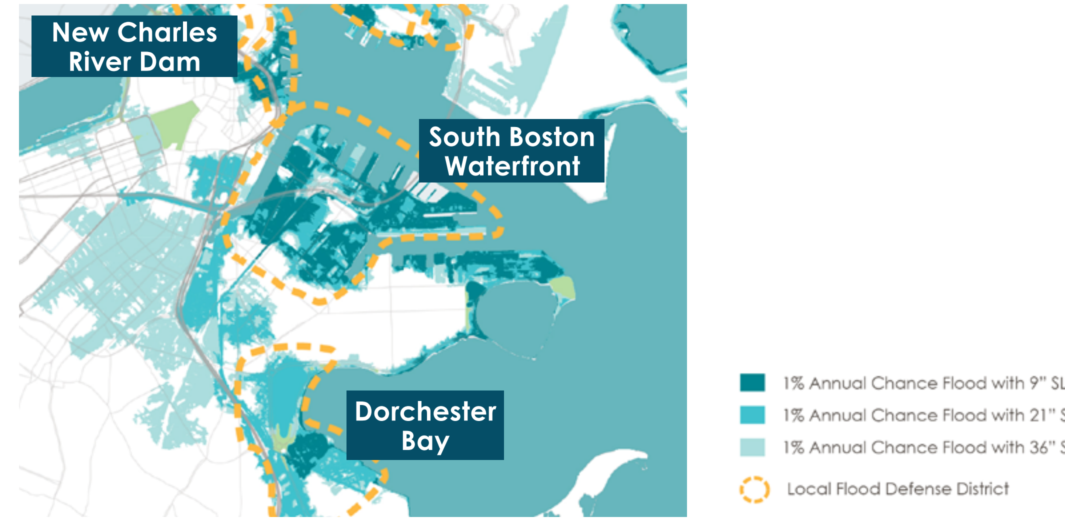
SLR SCENARIO	DISTRICT SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD[10]
9" SLR (2030s–2050s)	South Boston Waterfront
21" SLR (2050s–2100s)	South Boston Waterfront and Dorchester Bay locations combined
36" SLR (2070s or later)	South Boston Waterfront, Dorchester Bay, and the New Charles River Dam locations combined

LOCATIONS

- **The South Boston Waterfront location** focuses on flood entry points along the edge of the district, including flooding from Fort Point Channel, Boston Harbor, and the Reserve Channel. The low-lying nature of the South Boston Waterfront likely requires flood protection connections to high ground across Fort Point Channel. Potential flood protection solutions include a floodgate aimed at preventing storm surge from flowing into the South Boston Waterfront from Fort Point Channel. The gate could be placed at a number of locations, including the Northern Avenue Bridge, Seaport Boulevard Bridge, Congress Street Bridge, or Summer Street Bridge. The elevation of Summer Street on either side of the bridge is higher than the 1 percent annual chance flood event elevation with 36 inches of sea level rise (SLR), although other portions of Summer Street are lower. In addition to a gate across Fort Point Channel, flood protection solutions would require either a barrier system to connect to high ground south of West Broadway, perimeter protection near the Reserve Channel, or a gate across the Reserve Channel. Deployable gates would be required at intersections. *As an alternative to flood protection for the entire South Boston Waterfront, a flood protection system along the southwestern portion of the Fort Point Channel could provide flood protection benefits for parts of South Boston, as well as other areas, from Fort Point Channel flooding. However, since protection for the entire South Boston Waterfront would provide much greater benefit in both the near term and the long term, this Fort Point Channel alternative is unlikely to be necessary. Flood entry points from the southwestern portion of the Fort Point Channel should still be considered among planning and redevelopment projects in the area and potentially addressed in order to provide multiple lines of flood protection for inland areas.*
- **The Dorchester Bay location,** described in the Dorchester focus area (see p.194), addresses flood pathways from the Old Harbor and Savin Hill Cove.
- **The New Charles River Dam location,** described in the Charles River and Downtown focus areas (see pp. 174, 216), addresses potential overtopping or flanking of the dam.

[9]These preliminary coastal flood protection concepts are based on a high-level analysis of existing topography, rights-of-way, and urban and environmental conditions. Important additional factors, including existing drainage systems, underground transportation and utility structures, soil conditions and zoning as well as any potential external impacts as a result of the project have not been studied in detail. As described in Initiatives 5-2 and 5-3 (see p.106,110), detailed feasibility studies, including appropriate public and stakeholder engagement, are required in order to better understand the costs and benefits of flood protection in each location.

[10] Additional flood protection may be required for flood events more severe than the 1 percent annual chance flood. See Appendix for more detailed information on expected effectiveness of flood protection systems, including analysis of additional flood protection locations and flood frequencies.



DETAILED CONSIDERATIONS

- **Significant near-term benefits within a single neighborhood:** Given the South Boston Waterfront's high level of exposure to coastal flooding, flood protection at this location would provide meaningful protection at 9 inches of SLR for the 1 percent annual chance event and more frequent events. In the near term, flooding expected from very low-probability events (0.1 percent annual chance) may require interventions at Dorchester Bay, though further analysis is required to confirm the nature of this risk.
- **Need for multiple alignments in the second half of the century:** In the mid-century, South Boston Waterfront protection may need to be combined with Dorchester Bay protection to provide protection for South Boston, the South End, and Dorchester, due to flooding from the Boston Harbor, Fort Point Channel, the Reserve Channel, and Dorchester Bay. As soon as the 2070s, additional interventions at the New Charles River Dam will be necessary to protect the aforementioned neighborhoods from Charles River flooding expected at the 1 percent annual chance event.

PREPARED & CONNECTED COMMUNITIES

CONDUCT AN OUTREACH CAMPAIGN TO PRIVATE FACILITIES THAT SERVE VULNERABLE POPULATIONS TO ENSURE THAT THEY ENGAGE IN EMERGENCY PREPAREDNESS AND ADAPTATION PLANNING

The City should conduct outreach to managers of facilities in South Boston that serve significant concentrations of vulnerable populations and are not required to have operational preparedness and evacuation plans under current regulations. Targeted facilities will include affordable housing complexes, substance abuse treatment and rehabilitation centers, daycare facilities, food pantries, small nonprofit offices, and others. Illustrative examples of the types of facilities to which the City might conduct outreach include the Tiny Tots daycare facility on Columbia Road, the Harborview Children's Center, Bright Horizons at Seaport, and South Boston Head Start. These facilities are exposed to near-term damage from sea level rise and coastal flooding or can expect access issues related to near-term stormwater flooding.

EXPAND BOSTON'S SMALL BUSINESS PREPAREDNESS PROGRAM

The City should reach out to small businesses in South Boston exposed to stormwater flooding in the near term or coastal flooding under a 1 percent annual chance event at 9 inches of SLR to help them develop business continuity plans, evaluate insurance coverage needs, and identify low-cost physical adaptations. Under a 1 percent annual chance event at 9 inches of SLR, 88 commercial buildings and 131 mixed-use buildings that could host small businesses are exposed to flood risk. Though South Boston's primary commercial corridor along Broadway is located along high ground and is not exposed to flooding under the 1 percent annual chance event even with 36 inches of SLR, substantial numbers of small businesses in City Point, Telegraph Hill, and the South Boston Waterfront adjacent to new office developments are exposed under 9 inches of SLR.

[11] The City did not review the extent of existing preparedness planning as part of this study.

RESILIENT INFRASTRUCTURE

ESTABLISH INFRASTRUCTURE COORDINATION COMMITTEE

The Infrastructure Coordination Committee (ICC) should support coordinated adaptation planning for South Boston's key infrastructure systems, including energy, transportation, water and sewer, and environmental assets. The City should support the MBTA in conducting a full asset-level vulnerability assessment of its system, including the Red Line and Silver Line. Though neither of South Boston's two Red Line stops (Broadway and Andrew) are exposed to coastal flooding at 9 inches of SLR under the 1 percent annual chance flood event, flooding of tunnels and stops in Downtown Boston could impede the ability of residents to access jobs and essential services. The Silver Line has significant exposure to flooding at 9 inches of SLR under the 1 percent annual chance flood event

PRIORITIZE AND STUDY THE FEASIBILITY OF DISTRICT-SCALE FLOOD PROTECTION

The Office of Emergency Management should work with the Boston Transportation Department, Department of Public Works, and private utilities to provide guidance on critical roads to prioritize for adaptation planning, including evacuation routes and roads required to restore or maintain critical services. South Boston has four evacuation routes that are exposed at 9 inches of SLR under the 1 percent annual chance flood event, including Haul Road, Summer Street, Ted Williams Tunnel, and Congress Street. It is important to prepare roads in South Boston to avoid islanding in the later century.

CONDUCT FEASIBILITY STUDIES FOR COMMUNITY ENERGY SOLUTIONS

The 2016 Boston Community Energy Study identified East Broadway near Emerson Street as a potential location for an emergency microgrid, based on its concentration of critical facilities. The Environment Department will work with local stakeholders and utility providers to explore this location. The site is not exposed to expected coastal storm impacts in this century. The City also has been exploring the opportunity for a pilot microgrid project at Ray Flynn Marine Park. The proposed site is significantly exposed to coastal and stormwater flooding in the near term, and the City should consider climate change impacts in its planning process.

ADAPTED BUILDINGS

PROMOTE CLIMATE READINESS FOR PROJECTS IN THE DEVELOPMENT PIPELINE

Upon amending the zoning code to support climate readiness (see Initiative 9-2, p.135), the Boston Planning and Development Agency (BPDA) should immediately notify all developers with projects in the development pipeline in the future floodplain that they may alter their plans in a manner consistent with the zoning amendments (e.g., elevating their first-floor ceilings without violating building height limits), without needing to restart the BPDA permitting process.

The South Boston Waterfront is one of the most active development locations in Boston. Currently, 91 residential and 34 commercial buildings are under construction or permitted in South Boston, representing 3,900 additional housing units and 1.4 million square feet of new commercial space. In addition, General Electric is building a new headquarters facility adjacent to Fort Point Channel, the Massachusetts Convention and Exhibition Center has been proposed for expansion, and the Massachusetts Port Authority is offering a 23-acre site for development in the Massport Marine Terminal, making it critical to focus on building resilience now.

INCORPORATE FUTURE CLIMATE CONDITIONS INTO AREA PLANS AND ZONING AMENDMENTS

The Boston Planning and Development Agency should incorporate future climate considerations (long-term projections for extreme heat, stormwater flooding, and coastal and riverine flooding) into major planning efforts in South Boston. The City and state are funding a $100 million redesign and reconstruction of the Northern Avenue Bridge. In addition, the state is dedicating $25 million to improve pedestrian and bicycle infrastructure in South Boston and considering building an underground tunnel for buses at D Street. The City is currently leading a planning effort for the Dorchester Avenue Corridor between the Andrew and Broadway MBTA Stations. The City also is pursuing implementation of the 100 Acres Plan, completed in 2006.

ESTABLISH A CLIMATE READY BUILDINGS EDUCATION PROGRAM FOR PROPERTY OWNERS, SUPPORTED BY A RESILIENCE AUDIT PROGRAM

The City should develop and run a Climate Ready Buildings Education Program and a resilience audit program to inform property owners about their current and future climate risks and actions they can undertake to plan for these risks. To address the most immediate risks, the City should prioritize audits for buildings with at least a 1 percent annual chance of exposure to coastal and riverine flooding in the near term, under 9 inches of sea level rise. In South Boston, this includes 353 structures, with 41 percent of these consisting of residential and mixed-use buildings that house residents. A resilience audit should help property owners identify cost-effective, building-specific improvements to reduce flood risk, such as backflow preventers, elevation of critical equipment, and deployable flood barriers; promote interventions that address stormwater runoff or the urban heat island effect, such as green roofs or "cool roofs" that reflect heat; and encourage owners to develop operational preparedness plans and secure appropriate insurance coverage. The resilience audit program should include a combination of mandatory and voluntary, market-based and subsidized elements.

PREPARE MUNICIPAL FACILITIES FOR CLIMATE CHANGE

The Office of Budget Management should work with City departments to prioritize upgrades to municipal facilities in South Boston that demonstrate high levels of vulnerability (in terms of the timing and extent of exposure), consequences of partial or full failure, and criticality (with highest priority for impacts on life and safety) from coastal flooding in the near term. In the near term, at 9 inches of SLR, the EMS Harbor Unit, Boston Police Department Harbor Patrol Unit, and the Boston Marine Industrial Park, which is owned by the BRA, are exposed under the 1 percent annual chance flood event. In addition, the Boston Housing Authority Old Colony, Mary Ellen McCormack, and West Ninth Street housing developments will be exposed to coastal flooding in the second half of the century.

ESTABLISH A CLIMATE READY BUILDINGS EDUCATION PROGRAM FOR PROPERTY OWNERS, SUPPORTED BY A RESILIENCE AUDIT PROGRAM.

The City should develop and run a Climate Ready Buildings Education Program and a resilience audit program to inform property owners about their current and future climate-related risks, and actions they can undertake to address these risks. To address the most immediate risks, the City should prioritize audits for buildings with at least a one percent annual chance of exposure to coastal and riverine flooding in the near term, under nine inches of sea level rise. In South Boston, this includes 353 structures, with 41% of these consisting of residential and mixed-use buildings that house residents.

A resilience audit should help property owners identify cost-effective, building-specific improvements to reduce flood risk, such as backflow preventers, elevation of critical equipment, and deployable flood barriers; promote interventions that address stormwater runoff or the urban heat island effect, such as green roofs or "cool roofs" that reflect heat; and encourage owners to develop operational preparedness plans and secure appropriate insurance coverage.

The resilience audit program should include a combination of mandatory and voluntary, market-based and subsidized elements.

South End

The South End is located to the southwest of Fort Point Channel, southeast of the Back Bay neighborhood, and north of Roxbury and Dorchester.

The South End was built on fill starting in 1849. Washington Street, which extends through the South End, was the original street connecting Boston (the Shawmut Peninsula) to Roxbury, along the narrow "Great Neck." The South End was designed to be a residential district for upper-middle-class households, with brick row houses organized around small parks, to relieve housing pressures in Downtown and Beacon Hill. The majority of the construction occurred between 1850 and 1880. With the development of the Back Bay in the 1880s, the South End experienced new competition for upper-middle-class households.

During the late nineteenth century and early twentieth century, the South End received an influx of working-class immigrants. In the early 1900s, the Washington Street Elevated rail line opened, running from Chinatown to Dudley Square and then ultimately to Forest Hills.

During the 1960s and 1970s, the area became subject to urban renewal efforts. The state acquired land along a 4.6-mile route in the South End, Roxbury, and Jamaica Plain, with the intent of building a new section of I-95 (the Southwest Expressway) into Downtown Boston along the former Penn Central/New Haven Railroad right-of-way. Community protests caused the project to be halted. From 1979 to 1987, the land was used to reroute the MBTA Orange Line, and the Southwest Corridor Park was constructed on top. The Washington Street Elevated rail line, the last remaining elevated section of the Orange Line, was subsequently removed.

With the construction of the Prudential Center tower in 1964 and the Copley Place retail, office, and hotel complex in 1983, market pressures started to bleed over into the South End. The neighborhood experienced reinvestment from the 1970s onward, intensifying over time. Reflecting market pressures, the neighborhood has been the site of several innovative projects to preserve affordable housing. The Villa Victoria project, consisting of 435 low-income housing units, was completed during the 1970s, by the Inquilinos Boricuas en Acción community development corporation, using land provided by the Boston Redevelopment Authority. The Tent City project, consisting of 269 units of mixed-income housing, was completed in 1988, on land originally planned for a parking garage.

Today, the South End remains a primarily residential neighborhood. The housing stock consists of historic brick row houses, several public housing developments, and some infill, including the recent Ink Block project, a reuse of the Boston Herald site. The South End has main commercial corridors on Tremont Street, Columbus Avenue, and Washington Street, the last of which is a Main Streets district. The neighborhood has major employment hubs at the Boston Medical Center and Boston University School of Medicine and has experienced an expansion of biotech light manufacturing. The area is primarily served by the Orange Line, as well as the Silver Line, which opened in 2002 and runs along Washington Street and connects Downtown Crossing to Dudley Square.

Image courtesy of Sasaki

CC Image courtesy of pacoseoaneperez on Flickr

FLOOD PROGRESSION

DEFINITIONS

Near term: Beginning 2030s, assumes 9 inches of sea level rise

Midterm: Beginning 2050s, assumes 21 inches of sea level rise

Long term: Beginning 2070s or later, assumes 36 inches of sea level rise

Exposure: Can refer to people, buildings, infrastructure, and other resources within areas likely to experience hazard impacts. Does not consider conditions that may prevent or limit impacts.

Vulnerability: Refers to how and why people or assets can be affected by a hazard. Requires site-specific information.

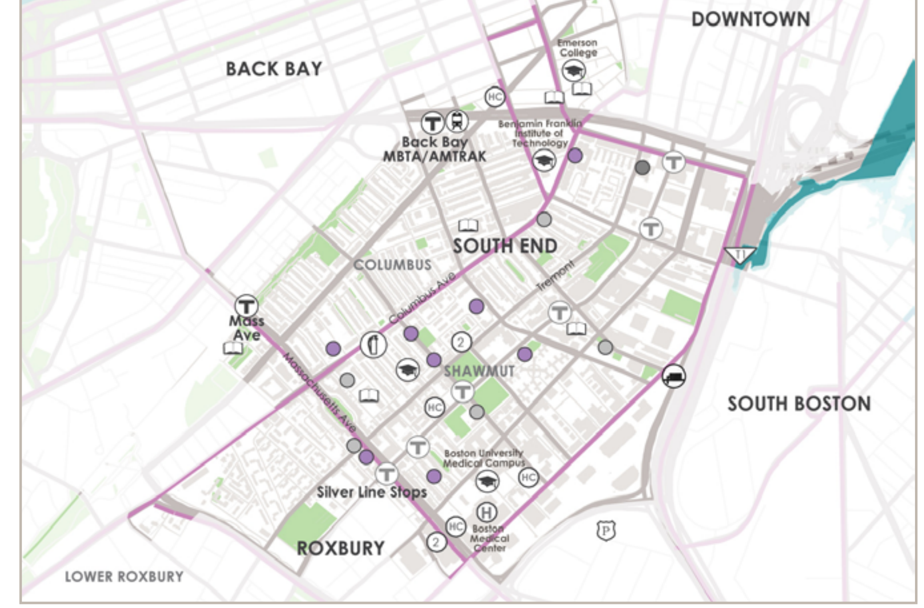
Consequence: Illustrates to what extent people or assets can be expected to be affected by a hazard, as a result of vulnerability and exposure. Consequences can often be communicated in terms of economic losses.

Annualized losses: The sum of the probability-weighted losses for all four flood frequencies analyzed for each sea level rise scenario. Probability-weighted losses are the losses for a single event times the probability of that event occurring in a given year.

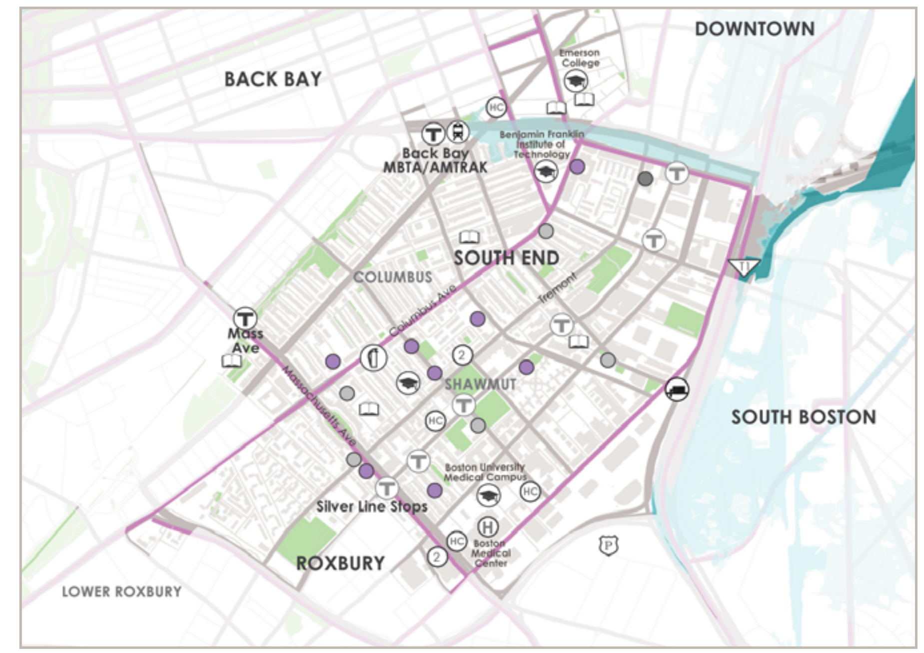
*For a full list of definitions, refer to the Glossary in the Appendix.

The South End is exposed to climate change impacts including heat, increased precipitation and stormwater flooding, and sea level rise and coastal and riverine flooding. Exposure to heat and stormwater flooding are addressed in the Citywide Vulnerability Assessment (see p.12), while exposure and consequences to coastal and riverine flood risk are further discussed in this section.

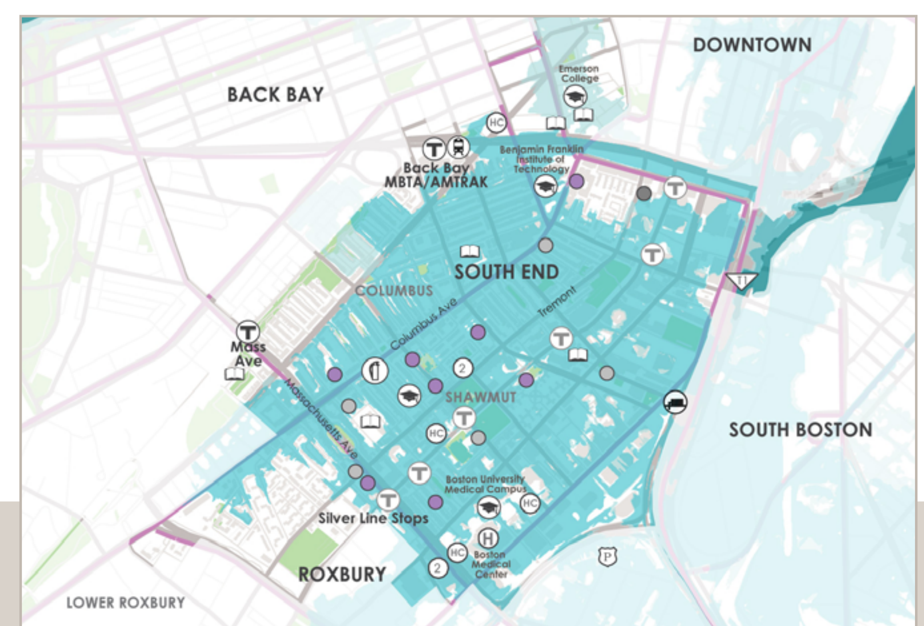
The South End will have limited exposure to coastal flooding until the second half of the century, when very low-probability coastal storms occur (0.1 percent annual chance event). Exposure to these storms and the 1 percent annual chance event later in the century is significant due to a flood pathway through Fort Point Channel. Flooding is expected to be severe enough to flood portions of Roxbury.



9 INCHES SEA LEVEL RISE



21 INCHES SEA LEVEL RISE



36 INCHES SEA LEVEL RISE

LEGEND

- Highest Monthly High Tide
- 10% Storm Flooding
- 1% Storm Flooding
- Roads
- Major Roads
- Major Tunnels
- Evacuation Route
- Evacuation Route Tunnels
- Parks
- MBTA Silver Line Station
- MBTA Station
- I-93 North Tunnel Entrance
- I-93 North Tunnel Entrance
- College or University
- School
- Hospital
- Health Care Facility
- Pump Station/Electric Substation
- Grove Hall Community Center
- Shelburne Community Center
- Vine St Community Center
- Blackstone Community Center
- Cooper Community Center
- BHA Public Housing
- Senior Housing
- Longterm Care Facility

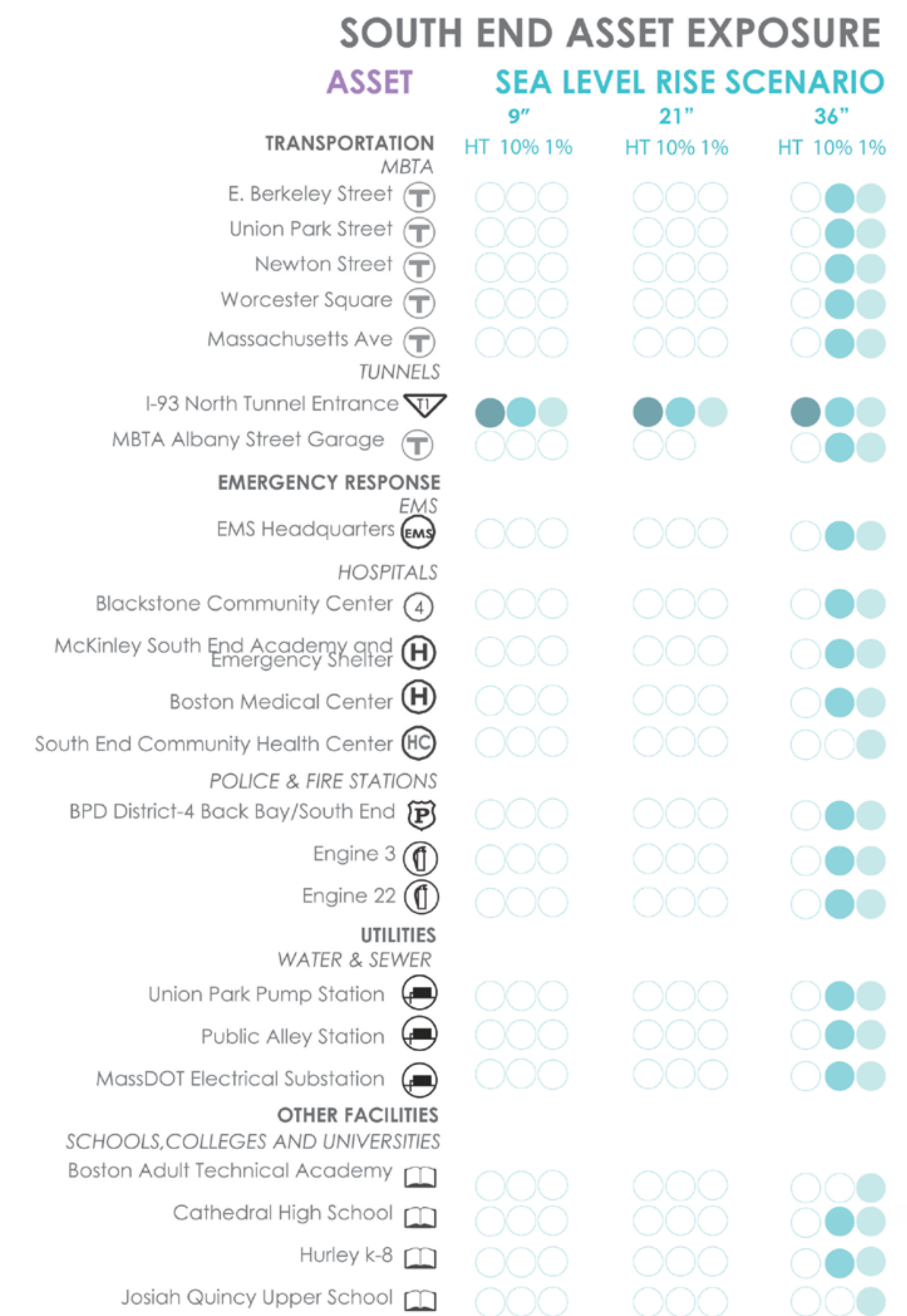
Until the middle of the century, the South End is expected to have limited exposure to coastal flooding. **Flooding originates from the coast through relatively narrow and few penetration points. Nevertheless, a topographic threshold is expected to be breached as a result of coastal storms later in the century.** In this case, the topographic threshold refers to the point at which water overtops grade and descends into lower topography to inundate a large area of typically dry land. This threshold exists at the railroad crossing on the western side of Fort Point Channel[1] and will expose vast areas of the South End and some northern reaches of Roxbury as soon as the 2070s. Over 70 percent (450 acres) of the South End neighborhood alone will be exposed to low-probability flood events during this time period.

Though not as significant of a flood pathway as Fort Point Channel, there is some potential for flooding from Dorchester Bay through Joseph Moakley Park as soon as the 2070s. The topography around Joseph Moakley Park and I-93 is continuously low lying, potentially allowing floodwaters to propagate inland to the South End and Roxbury for coastal storm events with lower probability of occurrence (1 percent annual chance). This is particularly the case for long-duration events, like nor'easters.

Resilience planning must consider that the primary flood pathway for the South End is through Fort Point Channel. Opportunities may exist for flood protections that defend the South End and Roxbury, while also benefiting South Boston and Downtown.

Of all Boston focus areas, the South End has the greatest percentage of land area per neighborhood exposed to low-probability storms expected by the end of the century.

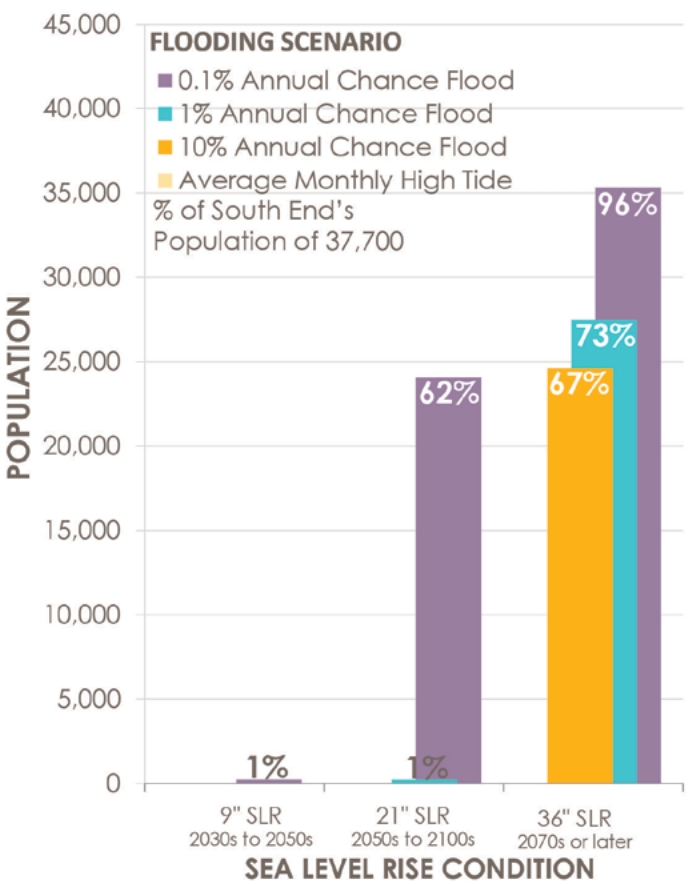
[1]MassDOT FHWA Report citation: Bosma, Kirk, et. al. "MassDOT-FHWA Pilot Project Report: Climate Change and Extreme Weather Vulnerability Assessments and Adaptation Options for the Central Artery." Jun. 2015, https://www.massdot.state.ma.us/Portals/8/docs/environmental/SustainabilityEMS/Pilot_Project_Report_MassDOT_FHWA.pdf.



EXPOSURE

POPULATION & INFRASTRUCTURE

SOUTH END POPULATION EXPOSURE



POPULATION AND SOCIAL VULNERABILITY

The South End is home to 38,600 people. While the South End boasts high residential real estate values and is generally considered an affluent area, it is home to more than 11,600 low-to no-income residents, 30 percent of the neighborhood population (higher than Boston's 28 percent average). Vulnerable populations in the South End are mostly concentrated in its more than 3,300 units of subsidized and public housing developments. The following public housing developments in the South End have at least some portion exposed to low-probability flood impacts later in the century: Cathedral, Torre Unidad, West Newton, Rutland, Frederick Douglas, Washington Manor, Hampton House, Camden, and Lenox. Together, they make up almost half of the South End's public housing stock.

As soon as the 2070s, almost 70 percent of the South End's population, 27,000 residents, will be exposed to flooding under low-probability events (1 percent annual chance).

Over 4,700 South End residents are expected to require shelter for this scenario. Current shelter capacity in the South End is 250 people. The South End's shelter capacity is likely to be further reduced in the case of a flood event. In the late century, the Blackstone Community Center and McKinley Elementary School, which serve as emergency shelters for the neighborhood, will be exposed to flooding from high-probability events, potentially reducing the neighborhood's current shelter capacity by more than 60 percent. There are two emergency shelters in the northern portion of Roxbury, which are not expected to be exposed to flood impacts and may be able to shelter residents from South End and South Boston, as needed.

INFRASTRUCTURE

Late in the century, the South End's major roads and evacuation routes, in addition to the Orange and Silver Line routes in the neighborhood, will be exposed to flooding, potentially compromising connectivity between Downtown and inland neighborhoods.

As soon as the 2050s, portions of the Orange Line routes through the South End will be exposed to flooding from low-probability events (1 percent annual chance); high-probability events expected later in the century (10 percent annual chance) will expose large sections of the Silver Line that run through the South End. The MBTA's Albany Street Garage is also exposed to flood impacts from low-probability events expected later in the century, which may affect the bus fleet that serves local routes, Mass Pike Express routes, and crosstown routes. These potential transportation impacts could hinder evacuation and disaster response operations in not only the South End but also in Downtown and South Boston. In the longer term, extended repairs to these systems could disrupt commutes back into these two economic centers.

Furthermore, important transportation corridors in the South End, including Tremont Street, Massachusetts Avenue, Albany Street, I-93 South, and Melnea Cass Boulevard at the border with Roxbury, all will have some portion exposed to flood impacts from high-probability flood events (10 percent annual chance) later in the century.

Boston Water and Sewer Commission operations depend upon uninterrupted power service in the South End and northern Roxbury areas.

In the South End, the Union Park pump station also may be exposed to high-probability flood impacts later in the century (10 percent annual chance event). The pump station is a combined sewer facility and has redundant pumps and generators in place to cover both mechanical and electrical failures, should they occur.

The South End may experience reduced emergency response capacity later in the century.

Throughout the South End, the EMS Headquarters, one Boston Police station, and two of three fire stations will be exposed to high-probability flood events as soon as the 2070s (10 percent annual chance). Widespread exposure in the area will also impact roads and complicate traveling for response vehicles, as described above.

Some of the area's top economic industries, the Boston Medical Center and Boston University Medical Campus, will be exposed to late-century flooding.

In the late century, the entire Boston Medical Center and Boston University Medical campus could be exposed to flood impacts, including the Menino Pavilion. The emergency room at the Menino Pavilion has the greatest volume of any trauma program in the Northeast, with more than 100,000 patients treated each year.[2] Full or partial service interruption at Boston Medical Center will likely have an effect on the nearest emergency medical facilities, including New England Baptist Hospital (which has announced that it is planning to relocate) or the VA Hospital, both in Mission Hill, as they endure the surge of relocated and redirected patients.[3]

[2] Source: Boston University. "The Menino Pavilion – Boston Medical Center." Website. Accessed August 2016. http://www.bumc.bu.edu/surgery/miscellani/bmc-menino-pavilion/

[3] A site-specific review of the Boston Medical Center is necessary.

EXPOSURE AND CONSEQUENCES
BUILDINGS AND ECONOMY

RISK TO BUILDINGS

Residential buildings located along Chandler Street are mostly split-level, three-story row houses and could experience significant flooding once waters are high enough to reach above grade.

In the near term, approximately 50 buildings in the South End are at risk to very low-probability, yet severe, coastal storms (0.1 percent annual chance event). The first structures expected to be impacted are located along Chandler Street, east of Clarendon, as well as just north of the Massachusetts Turnpike adjacent to Frieda Garcia Park. As soon as the 2050s, broad swaths of the South End neighborhood can be expected to be exposed to coastal flooding for the same event scenario.

The South End is in the top three exposed focus areas in Boston toward the end of the century, with close to $200 million in annualized structure damage and related losses possible.

As soon as the 2070s, high-probability coastal flood events (10 percent annual chance) may impact over 3,000 structures in the South End. The South End is also expected to experience the highest average flood depth inside structures citywide for the 1 percent annual chance flood event in the late century. The scale of loss to coastal flood impacts could potentially be mitigated through relatively inexpensive and focused projects to cut off flooding into the low-lying areas of the community.

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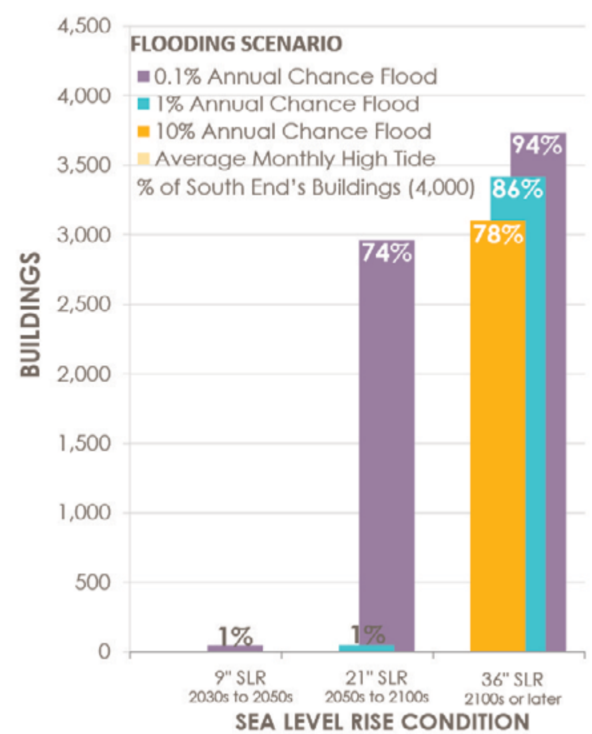
SOUTH END BUILDING EXPOSURE



SOUTH END MARKET VALUE EXPOSURE

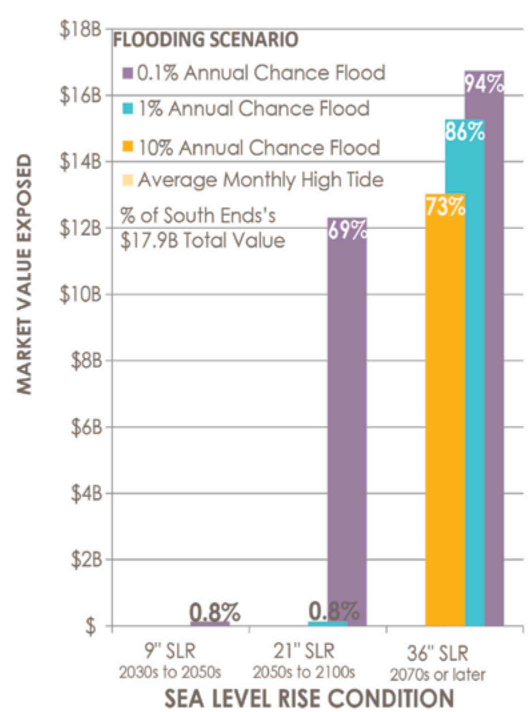


Image courtesy of Sasaki

RISK TO ECONOMY

The South End alone currently contributes over 20,000 jobs and $3.6 billion in output to the city's annual economy. Healthcare is the top industry in terms of both employment and output. Economic impacts to the communities are expected to be light until later in the century, when the topographic threshold described above is breached. As soon as the 2070s, unmitigated flood impacts could yield annualized output loss in excess of $60 million and annualized job loss around 330. The top affected industries at that point are expected to be real estate (due to the large areas of residential property impacted), hospitals, and restaurants. Restaurants are expected to experience the largest job impacts as a result of flooding late in the century.

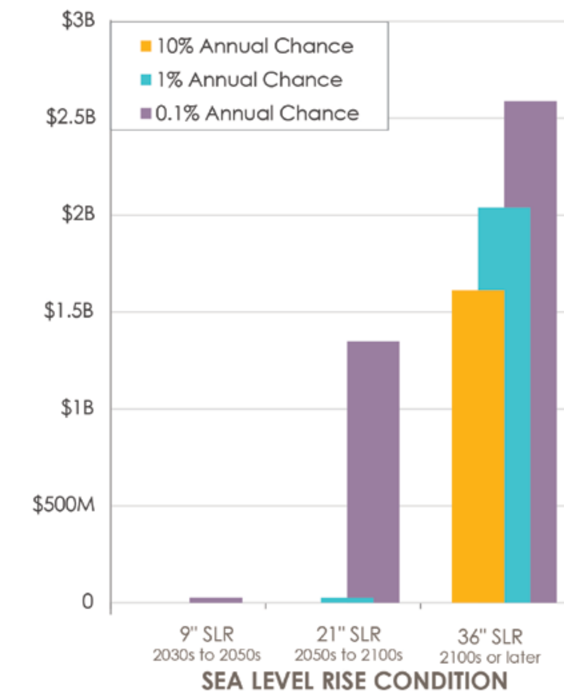
Though flooding originates from the coast through relatively narrow and few penetration points, a topographic threshold is expected to be breached sometime mid- to late century as a result of coastal storms. This would lead to over $200 million in annualized expected direct physical damage to structures and their contents late in the century.

ECONOMIC RISK ASSUMPTIONS

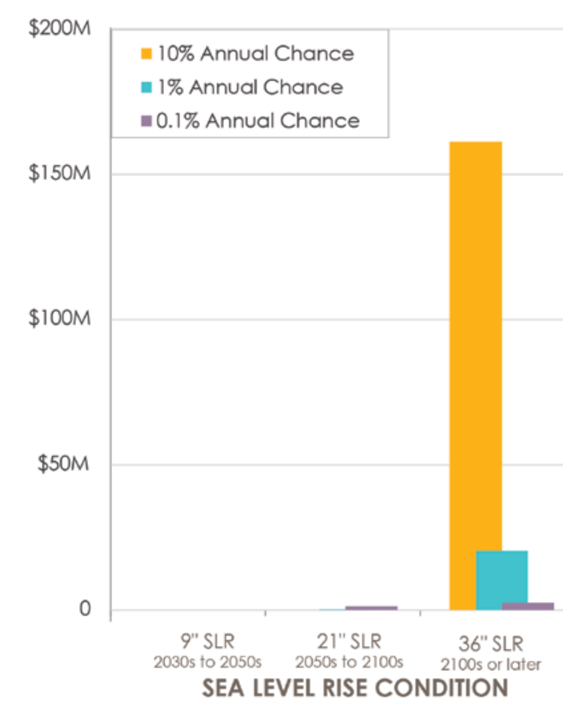
Job and output loss includes direct, indirect, and induced consequences of flood impacts. Direct results are impacts felt within a neighborhood, while indirect and induced results are those expected to be felt throughout Suffolk County as a result of changes in spending patterns. Results for both job and output losses are the sum of annualized values for the four flood frequencies analyzed for each sea level rise scenario. This represents a lower-bound estimate for several reasons. First, not all probabilistic events are considered. Second, the analysis assumes that all impacted businesses eventually reopen, though FEMA estimates that almost 40 percent of small businesses—and up to 25 percent of all businesses—never reopen after experiencing flood impacts. Third, only building areas directly impacted by floodwater are assumed to experience business interruption. This does not consider interruptions of businesses due to loss of power or utility functions. Finally, the analysis only considers existing populations, businesses, and buildings and does not include projections for future growth. Refer to the Appendix for a more detailed explanation of the exposure and consequence analysis.

INDUSTRY	ANNUALIZED LOSS OF ECONOMIC OUTPUT
Real estate	$12,100,000
Restaurants	$5,800,000
Hospitals and other medical facilities	$7,600,000
Wholesale trade and retail	$1,700,000
All other industries	$36,100,000
Total	**$61,600,000**

SOUTH END ECONOMIC LOSSES

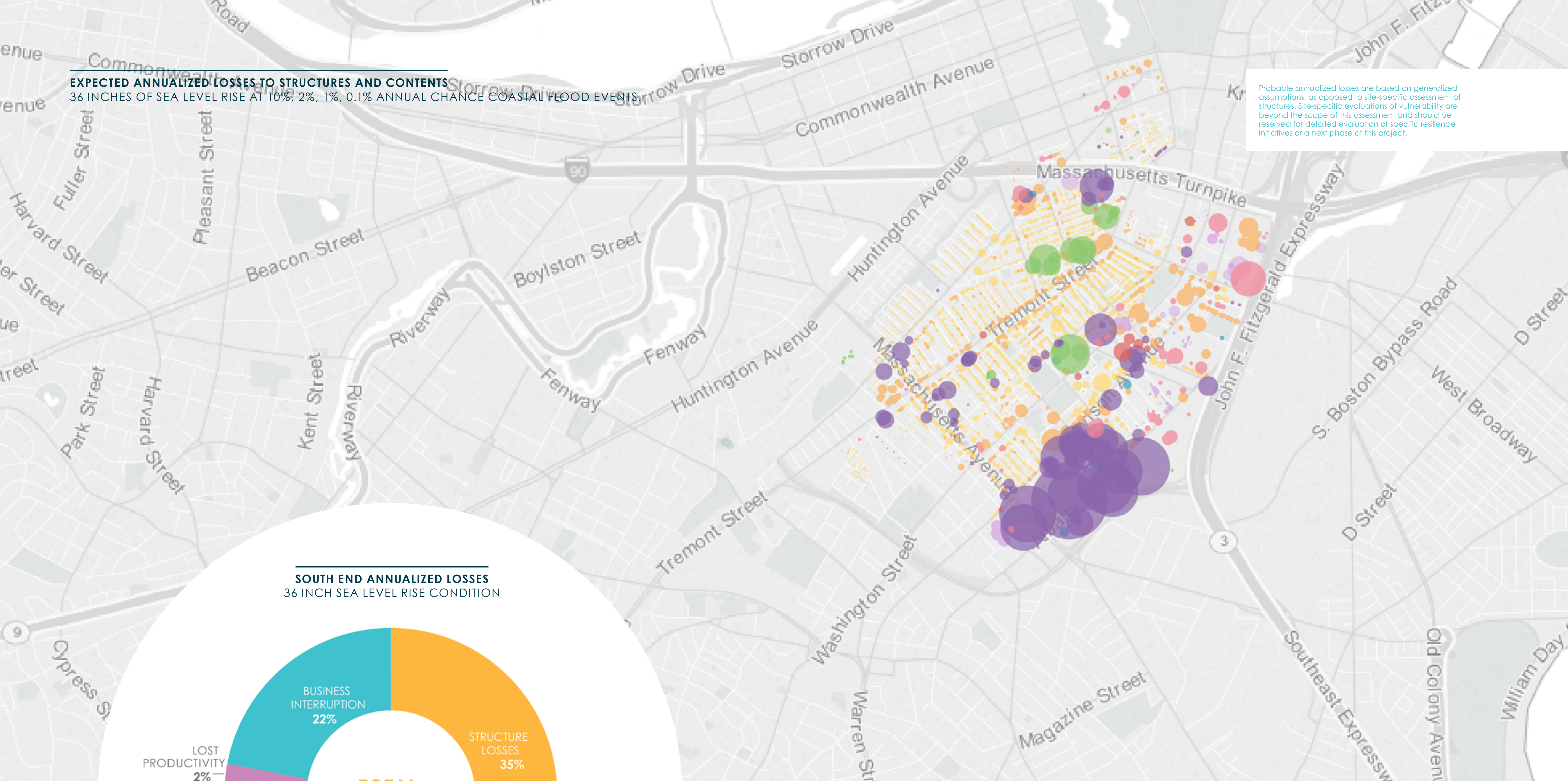


SOUTH END ANNUALIZED LOSSES



South End could experience the deepest average flood depth to flooded structures late in the century if flood risk goes unmitigated (1 percent annual chance flood event).

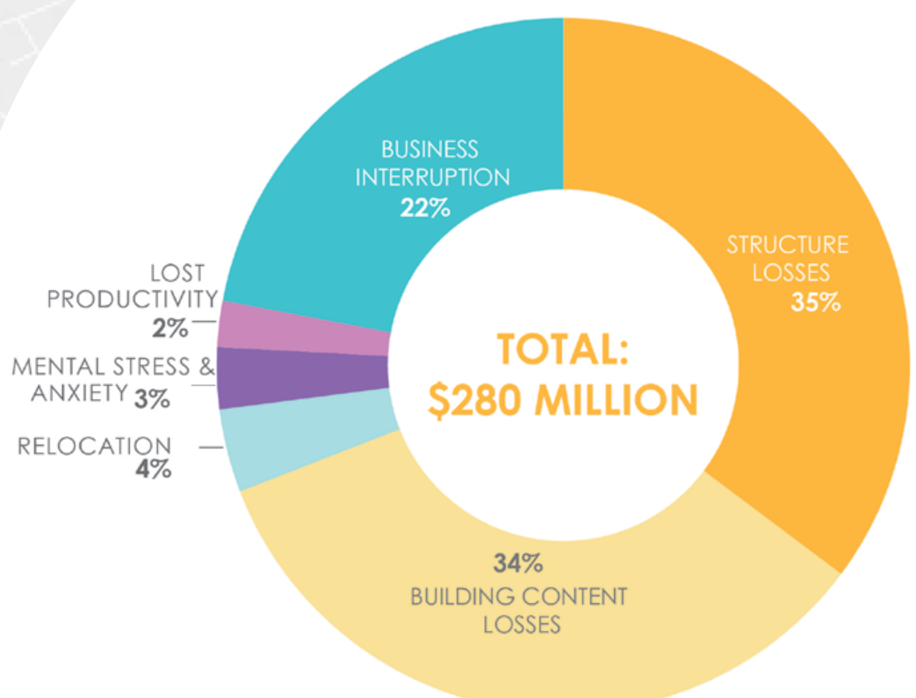
EXPECTED ANNUALIZED LOSSES TO STRUCTURES AND CONTENTS
36 INCHES OF SEA LEVEL RISE AT 10%, 2%, 1%, 0.1% ANNUAL CHANCE COASTAL FLOOD EVENTS



Probable annualized losses are based on generalized assumptions, as opposed to site-specific assessment of structures. Site-specific evaluations of vulnerability are beyond the scope of this assessment and should be reserved for detailed evaluation of specific resilience initiatives or a next phase of this project.

Each circle represents annualized losses suffered by an individual building. Larger circle size indicates higher contents and structures losses. Annualized losses take into consideration the annual probability of an event occurring, as well as the projected impacts of such an event.

SOUTH END ANNUALIZED LOSSES
36 INCH SEA LEVEL RISE CONDITION



PROTECTED SHORES

PRIORITIZE AND STUDY THE FEASIBILITY OF DISTRICT-SCALE FLOOD PROTECTION

To reduce the risk of coastal flooding at major inundation points, the City should study the feasibility of constructing district-scale flood protection at the primary flood entry points for the South End (see Potential Flood Protection Locations below for a preliminary identification of locations and potential benefits). As described below, flood protection systems that would benefit the South End would likely be located outside of the South End, in South Boston, Dorchester, and by the New Charles River Dam.

These feasibility studies should feature engagement with local community stakeholders, coordination with infrastructure adaptation, and considerations of how flood protection would impact or be impacted by neighborhood character and growth. Examples of prioritization criteria include the timing of flood risk, consequences for people and economy, social equity, financial feasibility, and potential for additional benefits beyond flood risk reduction.

POTENTIAL DISTRICT-SCALE FLOOD PROTECTION LOCATIONS[4]

See District-Scale Flood Protection Systems section for a citywide perspective on district-scale flood protection. District-scale flood protection is only one piece of a multi-layered solution that includes prepared and connected communities, resilient infrastructure, and adapted buildings.

[4] These preliminary coastal flood protection concepts are based on a high-level analysis of existing topography, rights-of-way, and urban and environmental conditions. Important additional factors, including existing drainage systems, underground transportation and utility structures, soil conditions, zoning, as well as any potential external impacts as a result of the project have not been studied in detail. As described in Initiatives 5-2 and 5-3, detailed feasibility studies, including appropriate public and stakeholder engagement, are required in order to better understand the costs and benefits of flood protection in each location.

In the near term, coastal flood risk in the South End is modest and likely does not require district-scale flood protection.

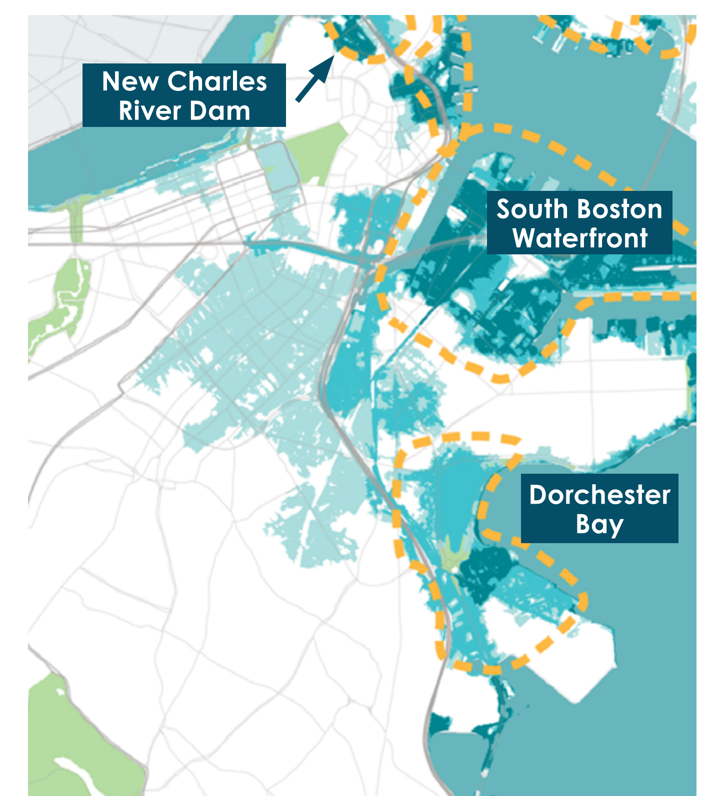
Later in the century, the South End will be exposed to flooding from Fort Point Channel and other inland flood pathways, so combined flood protection at multiple locations will be critical:

- At **Dorchester Bay,** addressing inland flood pathways originating from the Old Harbor and Savin Hill Cove.
- At the **South Boston Waterfront,** addressing inland flood pathways originating from Fort Point Channel, Boston Harbor, and the Reserve Channel
- At the **New Charles River Dam,** addressing potential overtopping or flanking of the dam.

SLR SCENARIO	DISTRICT SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD[5]
9" SLR (2030s–2050s)	None[6]
21" SLR (2050s–2100s)	The South Boston Waterfront and Dorchester Bay locations combined
36" SLR (2070s or later)	The New Charles River Dam, South Boston Waterfront, and Dorchester Bay locations combined

[5] Additional flood protection may be required for flood events more severe than the 1 percent annual chance flood. See Appendix for more detailed information on expected effectiveness of flood protection systems, including analysis of additional flood protection locations and flood frequencies.

[6] Benefits of district-scale flood protection would be modest.



LOCATIONS

- **The South Boston Waterfront location,** described in the South Boston focus area (see p.282), addresses flood entry points along the edge of the district. *As an alternative to flood protection for the entire South Boston Waterfront, a flood protection system along the southwestern portion of the Fort Point Channel could provide flood protection benefits for parts of South Boston, as well as other areas, from Fort Point Channel flooding. However, since protection for the entire South Boston Waterfront would provide much greater benefit in both the near term and the long term, this Fort Point Channel alternative is unlikely to be necessary. Flood entry points from the southwestern portion of the Fort Point Channel should still be considered among planning and redevelopment projects in the area and potentially addressed in order to provide multiple lines of flood protection for inland areas.*
- **The Dorchester Bay location,** described in the Dorchester focus area (see p.194), addresses flood pathways from the Old Harbor and Savin Hill Cove.
- **The New Charles River Dam location,** described in the Charles River and Downtown focus areas (see pp. 174, 216), addresses potential overtopping or flanking of the dam.

DETAILED CONSIDERATIONS

- Multiple locations required to address flood risk: For very low-probability events (0.1 percent annual chance) in the near term and into the second half of the century, flood exposure from both Fort Point Channel and Dorchester Bay are expected to impact portions of the South End, requiring district-scale flood protection solutions. Later in the century, flood protection solutions at the South Boston Waterfront and Dorchester Bay may not be independently effective for the 1 percent annual chance event and events with lower probability of occurrence, requiring interventions at the New Charles River Dam to impede flooding from the Charles River. While investments at all three locations may be significant, losses avoided are expected to be substantial because an integrated system could protect Downtown, South Boston, Dorchester, the South End, Roxbury, and neighborhoods along the Charles River.

PREPARED & CONNECTED COMMUNITIES

CONDUCT AN OUTREACH CAMPAIGN TO PRIVATE FACILITIES THAT SERVE VULNERABLE POPULATIONS TO ENSURE THAT THEY ENGAGE IN EMERGENCY PREPAREDNESS AND ADAPTATION PLANNING

In the long term, the City should conduct outreach to managers of facilities in the South End that serve significant concentrations of vulnerable populations and are not required to have operational preparedness and evacuation plans under current regulations. Targeted facilities will include affordable housing complexes, substance abuse treatment centers, daycare facilities, food pantries, small nonprofit offices, and others. The City should conduct outreach in the long term because widespread flooding in the neighborhood is not expected for the 1 percent annual chance flood event until later in the century, meaning that the South End focus area has a longer adaptation window. Illustrative examples of the types of facilities to which the City might conduct outreach include the Ellis Memorial Early Education and Care Program, Eagle's Nest Learning Center, and Pine Village Preschool. These facilities will be exposed to long-term damage from sea level rise and coastal flooding or can expect access issues related to stormwater flooding in the same time frame.

[7]The City did not review the extent of existing preparedness planning as part of this study.

PREPARED & CONNECTED COMMUNITIES

EXPAND BOSTON'S SMALL BUSINESS PREPAREDNESS PROGRAM

The City should reach out to small businesses in South Boston exposed to stormwater flooding risk in the near term to help them develop business continuity plans, evaluate additional insurance coverage needs, and identify low-cost physical adaptations. In the South End, there are approximately 30 commercial buildings and 180 mixed-use buildings that could host small businesses exposed to stormwater flooding in the near term. It is important to note that, in the near term, Tremont Street and Massachusetts Avenue, which are both key commercial corridors, will be exposed to stormwater flooding. The Washington Gateway Main Street District will also have portions exposed to stormwater flooding in the near term and will be exposed to coastal storm and sea level rise impacts during high-probability storms later in the century.

RESILIENT INFRASTRUCTURE

ESTABLISH INFRASTRUCTURE COORDINATION COMMITTEE

The Infrastructure Coordination Committee (ICC) should support coordinated adaptation planning for the South End's key infrastructure systems, including transportation, water and sewer, energy, telecommunications, and environmental assets. In the near term, the City should support the MBTA in conducting a full asset-level vulnerability assessment of its system.

PROVIDE GUIDANCE ON PRIORITY EVACUATION AND SERVICE ROAD INFRASTRUCTURE TO THE ICC

The Office of Emergency Management should work with the Boston Transportation Department, Department of Public Works, and private utilities to provide guidance on critical roads to prioritize for adaptation planning, including evacuation routes and roads required to restore or maintain critical services. With 21 inches of sea level rise, under the 1 percent annual chance flood event, portions of I-93 near Tremont Street, Arlington Street, and Berkeley Street will be exposed to coastal and riverine flooding.

CONDUCT FEASIBILITY STUDIES FOR COMMUNITY ENERGY SOLUTIONS

The 2016 Boston Community Energy Study identified three potential locations for Energy Justice or emergency microgrids: along Massachusetts Avenue, along Tremont Street, and at Public Alley 706. The Environment Department should work with local stakeholders and utility providers to explore these locations. All three locations have significant exposure to flooding under the 1 percent annual chance event with 36 inches of SLR.

ADAPTED BUILDINGS

PROMOTE CLIMATE READINESS FOR PROJECTS IN THE DEVELOPMENT PIPELINE

Upon amending the zoning code to support climate readiness (see Initiative 9-2, p.135), the Boston Planning and Development Agency (BPDA) should immediately notify all developers with projects in the development pipeline in the future floodplain that they may alter their plans in a manner consistent with the zoning amendments (e.g., elevating their first-floor ceilings without violating building height limits), without needing to restart the BPDA permitting process.

INCORPORATE FUTURE CLIMATE CONDITIONS INTO AREA PLANS AND ZONING AMENDMENTS

The Boston Planning and Development Agency should incorporate future climate considerations (long-term projections for extreme heat, stormwater flooding, and coastal and riverine flooding) into major planning efforts in the South End.

ESTABLISH A CLIMATE READY BUILDINGS EDUCATION PROGRAM FOR PROPERTY OWNERS AND ESTABLISH A RESILIENCE AUDIT PROGRAM

The City should develop and run a Climate Ready Buildings Education Program and a resilience audit program to inform property owners about their current and future climate risks and actions they can undertake to address these risks. A resilience audit should help property owners identify cost-effective, building-specific improvements to reduce flood risk, such as backflow preventers, elevation of critical equipment, and deployable flood barriers; promote interventions that address stormwater runoff or the urban heat island effect, such as green roofs or "cool roofs" that reflect heat; and encourage owners to develop operational preparedness plans and secure appropriate insurance coverage. The resilience audit program should include a combination of mandatory and voluntary, market-based and subsidized elements.

PREPARE MUNICIPAL FACILITIES FOR CLIMATE CHANGE

The Office of Budget Management should work with City departments to prioritize upgrades to municipal facilities in South End that demonstrate high levels of vulnerability (in terms of the timing and extent of exposure), consequences of partial or full failure, and criticality (with highest priority for impacts on life and safety) from coastal flooding in the near term. Later in the century, there are a number of Boston Housing Authority developments that are expected to be exposed to coastal flooding, as well as access issues related to stormwater flooding. These sites include Camden, Cathedral, Frederick Douglas, Hampton House, Lenox, Rutland/West Newton, Torre Unidad, and Washington Manor. The City will also prioritize adding backup power to emergency shelters that do not yet have power system redundancies. By later in the century, there will be a strong need for shelter capacity in the South End unless flood risk is mitigated, which will require all existing shelters to be prepared.

District-Scale Flood Protection Systems

A CITYWIDE PERSPECTIVE

Based on the citywide vulnerability assessment and the focus-area analyses, Climate Ready Boston proposes nine locations for flood-protection interventions. As sea level rises over the century, the number of interventions needed increases, and their cumulative effectiveness becomes more important.

KEY FINDINGS

The Progression of Flood Protection

In the near term, with nine inches of sea level rise, four flood protection systems, independent of one another, could protect against widespread one percent annual chance flooding: **East Boston;** the **New Charles River Dam**; the **Downtown Waterfront**; and the **South Boston Waterfront.**

As sea level rise progresses to 36 inches (2070s or later), preventing one percent annual chance flooding would require additional interventions:

- An expansion of the **East Boston** flood protection system;
- A **Charlestown** system near **Sullivan Square**;
- A **Downtown Waterfront** system; and
- A **combined flood protection system** for the **New Charles River Dam, the South Boston Waterfront, and Dorchester Bay.** This combined system will become necessary because low-lying inland areas and below-grade roads can bring floodwaters from the waterfront across the city.

[1] Important factors, including existing drainage systems, underground transportation and utility structures, soil conditions, zoning, as well as any potential external impacts as a result of the project have not been studied in detail.

[2] See Appendix for more detailed information on expected effectiveness of flood protection systems, including analysis of additional flood protection locations and flood frequencies.

[3] Annualized benefits can be used to determine project cost effectiveness by applying a discount rate to benefits, capital costs, and maintenance costs over the expected project useful life and evaluating the ratio of the net present value of benefits over costs. A ratio of one or greater typically indicates that a project is cost effective. A ratio less than one, for an evaluation that is based entirely on avoided damage costs, does not necessarily mean that a project is not worthwhile. Cost effectiveness is one lens through which to evaluate the merits of a project. These estimates consider current resident and structures in the study area, not future growth. For methodology see Appendix.

The Locations of Flood Protection

- A flood protection system that addresses the overtopping or flanking of the **New Charles River Dam** can reduce flood risk Downtown, in Charlestown, and along both sides of the Charles River.
- In **East Boston** and in **Charlestown**, targeted flood protection systems can address relatively narrow flood pathways.
- The low-lying portion of the **Downtown Waterfront** is very broad and densely built, which makes it challenging to identify a specific location for a flood protection system.
- Nearly the entire **South Boston Waterfront** is low-lying and exposed to flooding from three edges, presenting significant challenges to a flood protection system. A system that prevents flooding from Fort Point Channel can also benefit areas as far inland as the South End, **Roxbury, Newmarket, and Widett Circle.**
- Along **Dorchester Bay**, The broad, low-lying waterfront areas from **Joseph Moakley Park to Savin Hill Cove** also expose inland areas to flooding but do not present obvious, targeted solutions for flood protection systems.

Methodology

Based on existing topography, rights-of-way, and urban and environmental conditions, Climate Ready Boston identified locations where green or gray flood protection systems could protect populations and reduce damage to buildings, infrastructure, and the economy from the projected one percent annual flooding. This analysis is preliminary. As described in Initiatives 5-2 and 5-3, detailed feasibility studies and public and stakeholder engagement are required to better understand the costs and benefits of flood protection in each location.[1]

The three maps and accompanying tables on the following pages correspond to the three levels of sea level rise—9, 21, and 36 inches—assessed in this report. There are 9 potential intervention areas, described in more detail in the various focus area sections.[2] The accompanying tables provide preliminary, order-of-magnitude estimates of certain benefits[3] that could result from the implementation of the flood protection systems. They do not estimate potential costs.

This set of potential locations for district-scale flood protection is not comprehensive, and additional infrastructure may be necessary to protect specific sites. Additionally, district-scale flood protection is only one piece of a multi-layered solution that includes prepared and connected communities, resilient infrastructure, and adapted buildings.

9 INCHES SLR (2030–2050S)

DISTRICT-SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD

Jeffries Point to Central Square

(See East Boston Focus Area for more information)

Estimated Benefits

Benefiting Area[4]	
People	10,700
Structures	1,580
Land Area	260 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$186 million
Annualized across multiple flood probabilities[5]	$6 million

Downtown Waterfront

(See Downtown Focus Area for more information)

Estimated Benefits

Benefiting Area[6]	
People	1,100
Structures	170
Land Area	40 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$219 million
Annualized across multiple flood probabilities[7]	$21 million

New Charles River Dam

(See Downtown and Charlestown Focus Areas for more information)

Estimated Benefits

Benefiting Area[8]	
People	1,500
Structures	110
Land Area	90 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$314 million
Annualized across multiple flood probabilities[9]	$13 million

South Boston Waterfront

(See South Boston Focus Area for more information)

Estimated Benefits

Benefiting Area[10]	
People	2,300
Structures	290
Land Area	320 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$978 billion
Annualized across multiple flood probabilities[11]	$62 million

[4] Area protected through the 1% annual chance flood event. Additional flood protection would be necessary to protect against the 0.1% annual chance flood event.

[5] Probability-adjusted economic losses for the 1%, 2%, and 10% annual chance flood events. Additional flood protection locations would be necessary to protect against the 0.1% annual chance flood event.

[6] Area protected through the 0.1% annual chance flood event.

[7] Probability-adjusted economic losses for the 0.1%, 1%, 2%, and 10% annual chance flood events.

[8] Area protected through the 1% annual chance flood event. Additional flood protection would be necessary to protect against the 0.1% annual chance flood

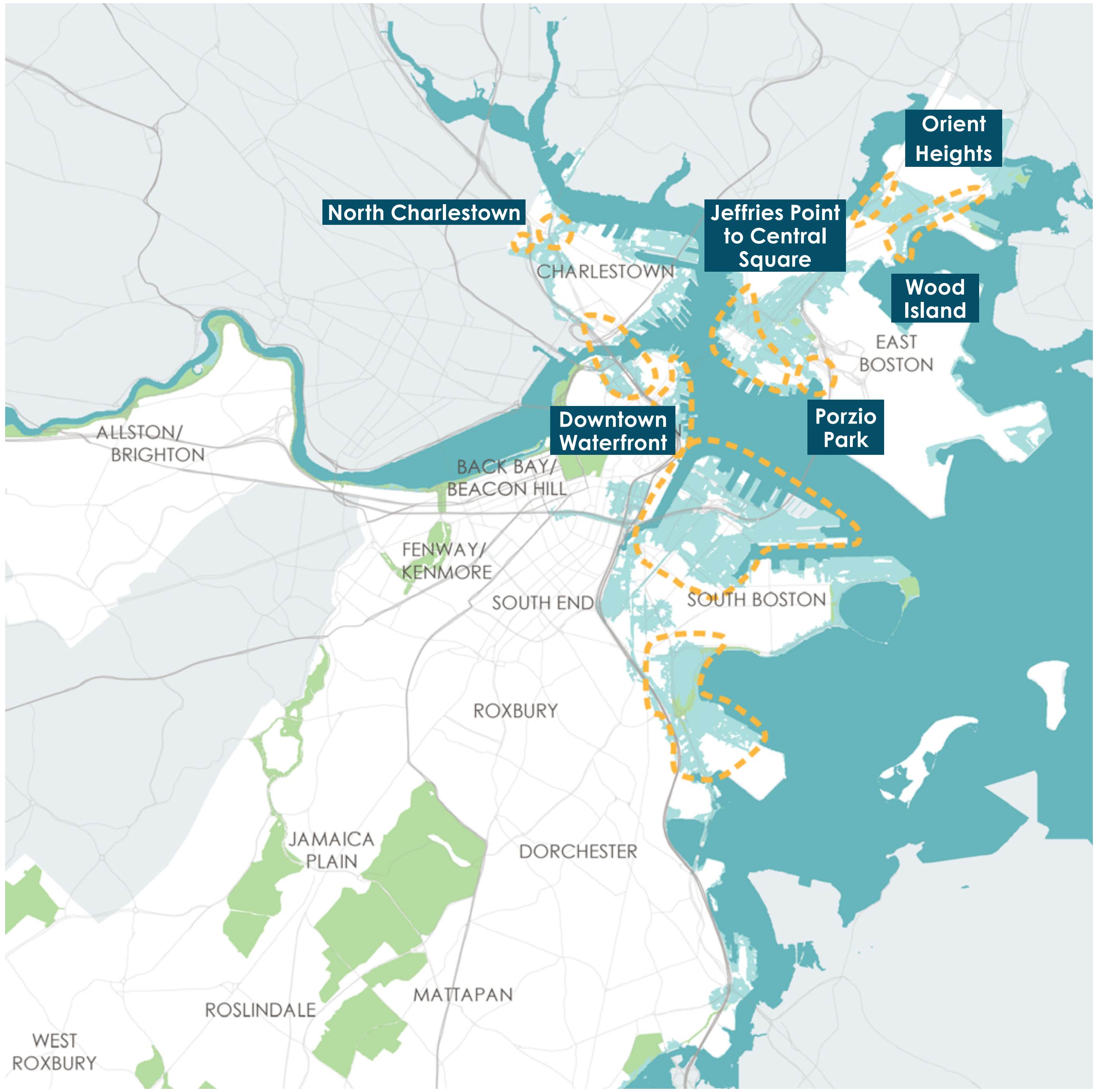
[9] Probability-adjusted economic losses for the 1%, 2%, and 10% annual chance flood events. Additional flood protection would be necessary to protect against the 0.1% annual chance flood event.

[10] Area protected through the 1% annual chance flood event. Additional flood protection would be necessary to protect against the 0.1% annual chance flood event.

[11] Probability-adjusted economic losses for the 1%, 2%, and 10% annual chance flood events. Additional flood protection locations would be necessary to protect against the 0.1% annual chance flood event.

21 INCHES SLR (2050S–2100S)

DISTRICT-SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD



Jeffries Point to Central Square

(See East Boston Focus Area for more information)

Estimated Benefits

Benefiting Area[12]	
People	10,500
Structures	1,560
Land Area	270 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$541 million
Annualized across multiple flood probabilities[13]	$36 million

North Charlestown and New Charles River Dam Locations Combined[16]

(See East Boston Focus Area for more information)

Estimated Benefits

Benefiting Area[17]	
People	21,200
Structures	4,310
Land Area	140 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$103 million
Annualized across multiple flood probabilities[18]	$3 million

Orient Heights

(See East Boston Focus Area for more information)

Estimated Benefits

Benefiting Area[14]	
People	2,700
Structures	470
Land Area	120 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$227 million
Annualized across multiple flood probabilities[15]	$23 million

Downtown Waterfront

(See Downtown Boston Focus Area for more information)

Estimated Benefits

Benefiting Area[19]	
People	1,100
Structures	200
Land Area	50 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$383 million
Annualized across multiple flood probabilities[20]	$39 million

[12] Area protected through the 1% annual chance flood event. Additional flood protection would be necessary to protect against the 0.1% annual chance flood event.

[13] Probability-adjusted economic losses for the 1%, 2%, and 10% annual chance flood events. Additional flood protection locations would be necessary to protect against the 0.1% annual chance flood event.

[14] Area protected through the 0.1% annual chance flood event.

[15] Probability-adjusted economic losses for the 0.1%, 1%, 2%, and 10% annual chance flood events.

[16] Only includes benefits in Charlestown. See table for New Charles River Dam for additional benefits citywide.

[17] Area protected through the 0.1% annual chance flood event.

[18] Probability-adjusted economic losses for the 0.1%, 1%, 2%, and 10% annual chance flood events.

[19] Area protected through the 0.1% annual chance flood event.

[20] Probability-adjusted economic losses for the 0.1%, 1%, 2%, and 10% annual chance flood events.

21 INCHES SLR (2050S–2100S)

DISTRICT-SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD

New Charles River Dam[21]

(See Downtown and Charlestown Focus Areas for more information)

Estimated Benefits

Benefiting Area[22]	
People	23,600
Structures	4,360
Land Area	290 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$543 million
Annualized across multiple flood probabilities[23]	$24 million

South Boston Waterfront and Dorchester Bay Locations Combined

(See South Boston and Dorchester Bay Focus Areas for more information)

Estimated Benefits

Benefiting Area[24]	
People	41,700
Structures	4,990
Land Area	1,580 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$3 billion
Annualized across multiple flood probabilities[25]	$218 million

[21] Does not include benefits in Charlestown, which are dependent on flood protection in North Charlestown. See table for North Charlestown and New Charles River Dam Locations Combined.

[22] Area protected through the 0.1% annual chance flood event.

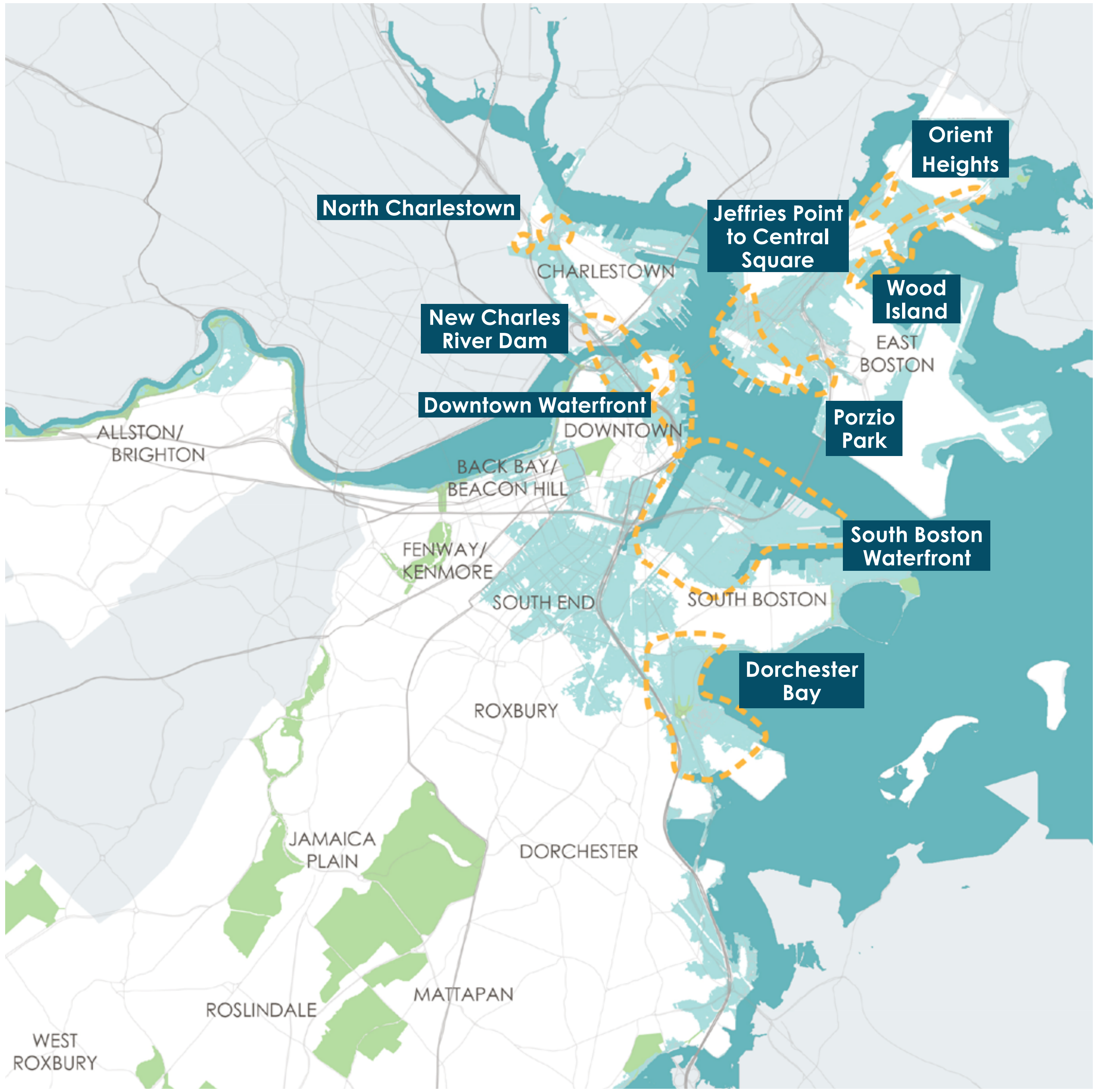
[23] Probability-adjusted economic losses for the 0.1%, 1%, 2%, and 10% annual chance flood events.

[24] Area protected through the 0.1% annual chance flood event.

[25] Probability-adjusted economic losses for the 0.1%, 1%, 2%, and 10% annual chance flood events.

36 INCHES SLR (2070S OR LATER)

DISTRICT-SCALE FLOOD PROTECTION FOR 1% ANNUAL CHANCE FLOOD



All Four East Boston Locations Combined

(See East Boston Focus Area for more information)

Estimated Benefits

Benefiting Area[26]	
People	14,800
Structures	2,430
Land Area	650 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$1.2 billion
Annualized across multiple flood probabilities[27]	$122 million

Downtown Waterfront

(See Downtown Focus Area for more information)

Estimated Benefits

Benefiting Area[31]	
People	1,100
Structures	230
Land Area	60 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$680 million
Annualized across multiple flood probabilities[32]	$71 million

North Charlestown and New Charles River Dam Locations Combined[28]

(See Charlestown Focus Area for more information)

Estimated Benefits

Benefiting Area[29]	
People	1,300
Structures	370
Land Area	170 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$238 million
Annualized across multiple flood probabilities[30]	$20 million

New Charles River Dam, South Boston Waterfront, and Dorchester Bay Locations Combined[33]

(See Downtown, Charlestown, South Boston and Dorchester Focus Areas for more information)

Estimated Benefits

Benefiting Area[34]	
People	114,100
Structures	10,620
Land Area	3,370 acres
Avoided Economic Losses	
From a single 1% annual chance flood	$9.4 billion
Annualized across multiple flood probabilities[35]	$912 million

[26] Area protected through the 0.1 percent annual chance flood event.

[27] Probability-adjusted economic losses for the 0.1 percent, 1 percent, 2 percent, and 10 percent annual chance flood events.

[28] Only includes benefits in Charlestown. See table for Locations 7, 8 and 9 Combined for additional benefits citywide.

[29] Area protected through the 0.1% annual chance flood event.

[30] Probability-adjusted economic losses for the 0.1%, 1%, 2%, and 10% annual chance flood events.

[31] Area protected through the 0.1% annual chance flood event.

[32] Probability-adjusted economic losses for the 0.1%, 1%, 2%, and 10% annual chance flood events.

[33] Does not include benefits in Charlestown, which are dependent on flood protection in North Charlestown. See table for North Charlestown and New Charles River Dam Locations Combined.

[34] Area protected through the 0.1% annual chance flood event.

[35] Probability-adjusted economic losses for the 0.1%, 1%, 2%, and 10% annual chance flood events.

Climate Ready Boston

Potential District-Scale Coastal Flood Protection Locations Appendix

CONTENTS

TABLES AND FIGURES

1. INTRODUCTION

Based on a high-level analysis of existing topography, rights-of-way, and current known urban and environmental conditions as of the summer of 2016, Climate Ready Boston (CRB) identified eleven locations where flood protection systems may provide significant flood risk reduction benefits, although detailed feasibility studies with appropriate public and stakeholder engagement are required in order to better understand the costs and benefits of flood protection in each location.[1] These eleven locations are outlined in Table 1 below. Please refer to Strategy 5 in **Protected Shores** for figures depicting proposed flood protection alignments.

Coastal and riverine hazard data for CRB consist of four flood frequencies (the 10, 2, 1, and 0.1 percent annual chance events) for three different sea level rise scenarios (9 inches, 21 inches, and 36 inches), resulting in twelve total flood scenarios. CRB analysts evaluated the following in order to develop a preliminary understanding of potential project effectiveness:

- Whether, and under which flood scenarios, each alignment could be expected to benefit an area independently or would need to be part of a system of multiple alignments in order to provide flood loss mitigation to the area
- Number of buildings expected to benefit from each proposed alignment or system of alignments
- Annualized[2] structure damage and contents losses preliminarily expected to be mitigated by each proposed alignment or system of alignments
- Number of residents expected to benefit from each proposed alignment or system of alignments
- Land area expected to benefit from each proposed alignment or system of alignments

CRB analysts evaluated independent effectiveness using the area of flood extent for each flood scenario, rather than depth grids. An alignment is no longer considered independently effective when flood waters from other inundation points begin to affect that alignment's benefitting area.

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[1] Important additional factors, including existing drainage systems, underground transportation and utility structures, soil conditions, zoning, as well as any potential external impacts as a result of the project have not been studied in detail.

[2] Annualized benefits can be used to determine project cost effectiveness by applying a discount rate to benefits, capital costs, and maintenance costs over the expected project useful life and evaluating the ratio of the net present value of benefits over costs. A ratio of one or greater typically indicates that a project is cost effective. A ratio less than one, for an evaluation that is based entirely on avoided damage costs, does not necessarily mean that a project is not worthwhile. Cost effectiveness is one lens through which to evaluate the merits of a project.

This Appendix provides a series of tables and figures to help the reader understand the approximate expected benefits that may occur as a result of protection alignments that block various flood sources throughout Boston. This includes:

- An overview of the locations of protection alignments (Table 1)
- A chart and short text explanation that provides the expected independent and system effectiveness of proposed alignments by flood scenario (Table 2)
- Tables with expected benefits for each protection alignment and system of alignments (Table 3 through Table 7). For more detail about how benefits are calculated, please refer to the **Approach and Methodology for Asset Data Collection and Exposure and Consequence Analysis Appendix**.

Note that each protection alignment, or necessary combination of alignments, has one table per sea level rise scenario. When a flood protection system is expected to become effective within a sea level rise scenario, benefits are presented in an additive way: each table represents the amount of benefit added by a certain protection alignment to a system rather than presenting the entire benefit of the whole system.

2. ANALYSIS LIMITATIONS

- These estimates consider present day[3] residents and structures in the area, derived using methods outlined in the Asset Data Collection and Exposure and Consequence Analysis Appendix, and do not consider future growth.
- This set of potential locations for district-scale flood protection is not meant to be comprehensive, and additional infrastructure may be necessary to protect specific sites. Additionally, potential district-scale flood protection actions are only one piece of a multi-layered solution that includes prepared and connected communities, resilient infrastructure, and adapted buildings.
- All values within this approach are estimates based on hypothetical and modeled hazard scenarios, and known and unknown data limitations exist. These limitations are described where known. Real impacts of coastal and riverine flooding will differ based on the particulars of the event as it happens.
- The flood protection solutions explored herein are intended to represent optional configurations of one type of mitigation action, and are not intended to be prescriptive. The

[3] Data collected in 2016, the contents of which are outlined within the Asset Data Collection and Exposure and Consequence Analysis Appendix

ultimate type and alignment of actions selected, as well as the timing and design of those actions, should follow a detailed technical and publicly engaged decision making process that considers factors in addition to flood risk mitigation (such as the social, technical, administrative, political, legal, economic, and environmental remifications of any potential solution).

TABLE 1. POTENTIAL FLOOD DEFENSE LOCATIONS AND DESCRIPTION

Alignment Number	Alignment Name	Potential Alignment Description
1	Piers Park to Central Square	Location 1 focuses on flood entry points along the western and southern edges of the East Boston waterfront. Potential flood protection solutions could consist of a north/south alignment connecting high points near Central Square and Lopresti Park and an east/west alignment connecting high points at Maverick Square and Jeffries Point. The north/south segment could potentially tie into existing green space at Lopresti Park and could help create new waterfront access points along East Boston's western edge. The east/west segment could potentially tie into existing and planned open spaces along the southern waterfront, such as Piers Park, Brophy Park, and Porzio Park.
2	Porzio Park	Location 2 focuses on a flood entry point in East Boston near where Jeffries Point meets Logan Airport. Potential flood protection solutions could connect high points at Sumner Street and Harborside Drive, near the entrance to the Ted Williams Tunnel, with the potential to tie in to existing green space along Massport's Harborwalk Park.
3	Wood Island	Location 3 focuses on flood entry points along the northern edge of Logan Airport, just east of the Wood Island T station in East Boston. Potential flood protection solutions could connect high points along Belle Isle Inlet to the northern part of Logan Airport, with the potential to tie into existing green spaces at Constitution Beach or Wood Island Bay Edge Park.
4	Orient Heights	Location 4 focuses on flood entry points near Constitution Beach and along Chelsea Creek in East Boston. Potential flood protection solutions could consist of two segments: an eastern segment by Constitution Beach, connecting high points near Byron Street and Barnes Avenue, and a western segment by Chelsea Creek, connecting high points near Boardman Street and Eagle Street.
5 and 6	Schrafft Center and Sullivan Square	Locations 5 and 6 focus on a major flood entry point at low ground between I-93 and Bunker Hill Street, near Sullivan Square in Charlestown. Potential flood protection solutions could include permanent boundary protection along Bunker Hill Street; temporary barriers at the intersection of Medford Street and Bunker Hill Street; Engine 32/Ladder 9 entrance, and Schrafft's building driveway; a deployable barrier for the Route 99 trench; regraded and elevated streets near flood entry points to provide perimeter boundary protection; and integrated flood protections and transportation improvements at Sullivan Square.
7	Downtown Waterfront	Location 7 is focused on flood entry points along the low-lying eastern edge of Downtown, starting in the North End and extending to the mouth of Fort Point Channel. Flood defense solutions could include a series of barriers, potentially encompassing floodwalls,

Alignment Number	Alignment Name	Potential Alignment Description
		greenways, or berms. Potential alignments include along the path of the Rose Kennedy Greenway, connecting high ground near Hanover Street in the north with high ground near Oliver Street in the south, or closer to the waterfront, with potential integration with Christopher Columbus Park.
8	New Charles River Dam	Location 8 addresses flooding by the Zakim Bridge/New Charles River Dam. Potential flood protection solutions could include a tide barrier across the mouth of Miller's River; a tide gate and connecting flood protection system just west of Littoral Way; or a deployable barrier across the railroad right-of-way connecting Charlestown and North Station.
9a	Seaport	Location 9a focuses on flood entry points along the edge of the Seaport District, including flooding from Fort Point Channel, Boston Harbor, and the Reserve Channel. The low-lying nature of the Seaport likely requires flood protection connections to high ground across Fort Point Channel. Potential flood protection solutions include a flood gate aimed at preventing storm surge from flowing into the Seaport District from Fort Point Channel. The gate could be placed at a number of locations, including the Northern Avenue Bridge, Seaport Boulevard Bridge, Congress Street Bridge, or Summer Street Bridge. The elevation of Summer Street on either side of the bridge is higher than the 1 percent annual chance flood event elevation with 36 inches of SLR, although other portions of Summer Street are lower. In addition to a gate across Fort Point Channel, flood protection solutions would require either a barrier system to connect to high ground south of West Broadway; perimeter protection near the Reserve Channel; or a gate across the Reserve Channel. Deployable gates would be required at intersections.
9b	Fort Point Channel	This location focuses on flooding along the southwestern portion of the Fort Point Channel, the primary flood pathway for the South End, northeastern Roxbury, and Widett Circle and Newmarket. Potential flood protection solutions could include an alignment along the northwestern edge of the channel, connecting high ground at the US Postal Service facility south of Summer Street to high ground near the Broadway Red Line station; partial filling-in of the channel, with a new waterfront edge that ties back to high ground on either side; or a tide gate crossing the Fort Point Channel.
10	Moakley Park/Columbia Point	Location 10 focuses on flood pathways along the Old Harbor and Savin Hill Cove. Potential flood protection solutions could include a landscaped berm or full elevation of Joe Moakley Park; a water-side alignment along William Day Boulevard; an alignment along Harbor Point; a landscaped berm or alignment running along the waterfront through Old Harbor Park; and an alignment along Old Colony Avenue. Flood defenses at Location 11 are most effective in combination with other defenses, but has potential to benefit Dorchester, South Boston, the South End, and southern portions of Downtown.

TABLE 2. COASTAL FLOOD PROTECTION ALIGNMENT AND SYSTEM EFFECTIVENESS CHART

Focus Area	Alignment Number	Alignment Name	9 inches of sea level rise				21 inches of sea level rise				36 inches of sea level rise			
			10%	2%	1%	0.1%	10%	2%	1%	0.1%	10%	2%	1%	0.1%
East Boston	1	Piers Park to Central Square					C(2)	C(2)	C(2)	C(2,3)	C(2,3)	C(2,3,4)	C(2,3,4)	C(2,3,4)
East Boston	2	Porzio Park					C(1)	C(1)	C(1)	C(1,3)	C(1,3)	C(1,3,4)	C(1,3,4)	C(1,3,4)
East Boston	3	Wood Island								C(1,2)	C(1,2)	C(1,2,4)	C(1,2,4)	C(1,2,4)
East Boston	4	Orient Heights										C(1,2,3)	C(1,2,3)	C(1,2,3)
Charlestown	5 and 6	Schrafft Center and Sullivan Square				C(8)		C(8)	C(8)	C(8)		C(8)	C(8)	C(8)
Downtown	7	Downtown Waterfront												
Downtown	8	New Charles River Dam											C(9,10)	C(9,10)
South Boston	9a[4]	Seaport				C(10)	C(10)	C(10)	C(10)	C(10)	C(10)	C(10)	C(8,10)	C(8,10)
South Boston	9b	Fort Point Channel				C(10)	C(10)	C(10)	C(10)	C(10)	C(10)	C(10)	C(8,10)	C(8,10)
Dorchester	10	Moakley Park/Columbia Point				C(9)	C(9)	C(9)	C(9)	C(9)	C(9)	C(9)	C(8,9)	C(8,9)

Legend

Alignment Expected to be Independently Effective	
Combination of Alignments [C] Expected to be Effective (single aligment expected to lose effectiveness due to expansion of flooded area under this scenario)	C(Alignment Numbers (#))
Limited Exposure to Coastal Flood Risk Expected at this Location	

[4] Reference to Alignment 9 alludes to either 9a or 9b, as the two alignments are meant to be altnerative choices to protect against Fort Point Channel flooding.

TABLE 3. EAST BOSTON FOCUS AREA PROTECTION SYSTEM BENEFITS

Potential Citywide Benefits	Location 1: Piers Park to Central Square 9" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$185,522,233
Annualized Losses Avoided	$6,003,968
Benefitting Structures	1581
Benefitting Population	10746
Benefitting Land Area (acres)	262

Potential Citywide Benefits	Location 1,2: Piers Park and Porzio Park 21" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$541,296,332
Annualized Losses Avoided	$36,325,210
Benefitting Structures	1560
Benefitting Population	10499
Benefitting Land Area (acres)	272

Potential Citywide Benefits	Location 1, 2, and 3: Piers Park, Porzio Park, and Wood Island 36" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	Locations 1,2, and 3 are not likely independent beyond the 10% annual chance event.
Annualized Losses Avoided	$62,994,225
Benefitting Structures	1716
Benefitting Population	11197
Benefitting Land Area (acres)	335

Potential Citywide Benefits	Location 2: Porzio Park 9" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$7,654,038
Annualized Losses Avoided	$373,686

Potential Citywide Benefits	Location 1, 2, and 3: Piers Park, Porzio Park, and Wood Island 21" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	Locations 1 and 2 are an effective combination for the 1% annual chance event. Locations 1, 2, and 3 potentially combine for the 0.1% chance with 21" of SLR.
Annualized Losses Avoided	$777,459

Potential Citywide Benefits	Location 1, 2, 3, and 4: Piers Park, Porzio Park, Wood Island, and Orient Heights 36" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$1,156,354,677
Annualized Losses Avoided	$121,907,421

Benefitting Structures	25
Benefitting Population	63
Benefitting Land Area (acres)	5

Benefitting Structures	1765
Benefitting Population	11324
Benefitting Land Area (acres)	408

Benefitting Structures	2432
Benefitting Population	14797
Benefitting Land Area (acres)	651

Potential Citywide Benefits	**Location 4: Orient Heights 9" SLR Scenario**
Avoided Losses for One-Time 1% Annual Chance Event	$1,235,358
Annualized Losses Avoided	$260,905
Benefitting Structures	443
Benefitting Population	2532
Benefitting Land Area (acres)	109

Potential Citywide Benefits	**Location 4: Orient Heights 21" SLR Scenario**
Avoided Losses for One-Time 1% Annual Chance Event	$227,103,477
Annualized Losses Avoided	$23,385,539
Benefitting Structures	473
Benefitting Population	2704
Benefitting Land Area (acres)	119

TABLE 4. CHARLESTOWN FOCUS AREA PROTECTION SYSTEM BENEFITS

Potential Citywide Benefits	Location 5: Schrafft Center 9" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$538,495
Annualized Losses Avoided	$11,233
Benefitting Structures	3
Benefitting Population	0
Benefitting Land Area (acres)	4

Potential Citywide Benefits	Location 5: Schrafft Center 21" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	Not independently effective beyond 10% annual chance event
Annualized Losses Avoided	$33,761
Benefitting Structures	3
Benefitting Population	0
Benefitting Land Area (acres)	4

Potential Citywide Benefits	Location 5: Schrafft Center 36" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	Not independently effective beyond 10% annual chance event
Annualized Losses Avoided	$12,316,428
Benefitting Structures	187
Benefitting Population	415
Benefitting Land Area (acres)	101

Potential Charlestown Benefits	Location 8: New Charles River Dam 9" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$3,618,888
Annualized Losses Avoided	$379,514
Benefitting Structures	1
Benefitting Population	0
Benefitting Land Area (acres)	3

Potential Charlestown Benefits	Location 8: New Charles River Dam 21" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	Not independently effective in Charlestown beyond 10% annual chance event
Annualized Losses Avoided	$361,889
Benefitting Structures	1
Benefitting Population	0
Benefitting Land Area (acres)	3

Potential Charlestown Benefits	Location 8: New Charles River Dam 36" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	Not independently effective in Charlestown beyond 10% annual chance event
Annualized Losses Avoided	$419,798
Benefitting Structures	1
Benefitting Population	0
Benefitting Land Area (acres)	4

Potential Charlestown Benefits	Location 5 and 8: Schrafft Center and New Charles River Dam 9" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	Locations 1 and 2 are independently effective at the 1%.
Annualized Losses Avoided	$112,413
Benefitting Structures	181
Benefitting Population	405
Benefitting Land Area (acres)	100

Potential Charlestown Benefits	Location 5 and 8: Schrafft Center and New Charles River Dam 21" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$102,703,155
Annualized Losses Avoided	$3,405,277
Benefitting Structures	309
Benefitting Population	1188
Benefitting Land Area (acres)	144

Potential Charlestown Benefits	Location 5 and 8: Schrafft Center and New Charles River Dam 36" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$237,635,636
Annualized Losses Avoided	$6,813,865
Benefitting Structures	367
Benefitting Population	1348
Benefitting Land Area (acres)	171

TABLE 5. DOWNTOWN WATERFRONT PROTECTION ALIGNMENT BENEFITS

Potential Citywide Benefits	Location 7: Downtown Waterfront 9" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$218,740,861
Annualized Losses Avoided	$21,244,379
Benefitting Structures	169
Benefitting Population	1079
Benefitting Land Area (acres)	36

Potential Citywide Benefits	Location 7: Downtown Waterfront 21" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$382,786,957
Annualized Losses Avoided	$39,355,237
Benefitting Structures	202
Benefitting Population	1099
Benefitting Land Area (acres)	49

Potential Citywide Benefits	Location 7: Downtown Waterfront 36" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$680,350,119
Annualized Losses Avoided	$70,671,741
Benefitting Structures	232
Benefitting Population	1100
Benefitting Land Area (acres)	60

TABLE 6. SOUTH BOSTON, DORCHESTER, CHARLES RIVER FOCUS AREA PROTECTION SYSTEM BENEFITS

Potential Citywide Benefits	Location 9a: Seaport 9" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$978,415,662
Annualized Losses Avoided	$61,914,366
Benefitting Structures	293
Benefitting Population	2275
Benefitting Land Area (acres)	324

Potential Citywide Benefits	Location 9a and 10: Seaport and Moakley Park/Columbia Point 21" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$29,892,972
Annualized Losses Avoided	$218,248,766
Benefitting Structures	4985
Benefitting Population	41684
Benefitting Land Area (acres)	1580

Potential Citywide Benefits	Location 9a and 10: Seaport and Moakley Park/Columbia Point 36" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	Not independently effective beyond 2% annual chance event.
Annualized Losses Avoided	$725,255,293
Benefitting Structures	5416
Benefitting Population	45227
Benefitting Land Area (acres)	1715

Potential Citywide Benefits	Location 10: Moakley Park/Columbia Point 9" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$37,408,373
Annualized Losses Avoided	$1,051,065
Benefitting Structures	27
Benefitting Population	0
Benefitting Land Area (acres)	37

Potential Mainland Benefits	Location 8: New Charles River Dam 21" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$543,040,169
Annualized Losses Avoided	$24,435,795
Benefitting Structures	363
Benefitting Population	3616
Benefitting Land Area (acres)	292

Potential Mainland Benefits	Location 8: New Charles River Dam 36" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	Not independently effective beyond 2% annual chance event.
Annualized Losses Avoided	$77,110,214
Benefitting Structures	498
Benefitting Population	4468
Benefitting Land Area (acres)	307

Potential Citywide Benefits	Location 9a and 10: Seaport and Moakley Park/Columbia Point 9" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	Alignments independently effective until 0.1% AEP
Annualized Losses Avoided	$2,732,886
Benefitting Structures	1281
Benefitting Population	13486
Benefitting Land Area (acres)	853

Potential Mainland Benefits	Location 8: New Charles River Dam 9" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$310,502,476
Annualized Losses Avoided	$13,037,146
Benefitting Structures	106
Benefitting Population	1484
Benefitting Land Area (acres)	85

Potential Mainland Benefits	Location 8,9a, and 10: New Charles River Dam, Seaport, and Moakley Park/Columbia Point 36" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$9,396,692,850
Annualized Losses Avoided	$109,251,308
Benefitting Structures	10621
Benefitting Population	114079
Benefitting Land Area (acres)	3365

TABLE 7. DORCHESTER, FORT POINT CHANNEL, CHARLES RIVER FOCUS AREA PROTECTION SYSTEM BENEFITS

Potential Citywide Benefits	Location 10: Moakley Park/Columbia Point 9" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$37,408,373
Annualized Losses Avoided	$1,051,065
Benefitting Structures	27
Benefitting Population	0
Benefitting Land Area (acres)	3

Potential Citywide Benefits	Location 9b and 10: Fort Point Channel and Moakley Park/Columbia Point 21" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$863,621,023
Annualized Losses Avoided	$40,715,589
Benefitting Structures	4543
Benefitting Population	37256
Benefitting Land Area (acres)	1021

Potential Citywide Benefits	Location 9b and 10: Fort Point Channel and Moakley Park/Columbia Point 36" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	Not independently effective beyond 2% annual chance event.
Annualized Losses Avoided	$394,966,176
Benefitting Structures	4967
Benefitting Population	40871
Benefitting Land Area (acres)	1146

Potential Citywide Benefits	Location 9b and 10: Fort Point Channel and Moakley Park/Columbia Point 9" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	Alignments independently effective until 0.1% AEP
Annualized Losses Avoided	$794,803
Benefitting Structures	897
Benefitting Population	10400
Benefitting Land Area (acres)	400

Potential Citywide Benefits (including Charlestown)	Location 9b, 10, and 8: Fort Point Channel, Moakley Park/Columbia Point, and Charles River Dam 36" SLR Scenario
Avoided Losses for One-Time 1% Annual Chance Event	$5,756,203,840
Annualized Losses Avoided	$68,565,747
Benefitting Structures	10150
Benefitting Population	109278
Benefitting Land Area (acres)	2765

Climate Ready Boston

Approach and Methodology for Asset Data Collection and Exposure and Consequence Analysis

CONTENTS

TABLES AND FIGURES

1. INTRODUCTION

The Climate Ready Boston (CRB) Vulnerability Assessment reviews three climate-related hazards and their plausible evolution over time to analyze how the City can expect people, property, infrastructure, and the economy to be affected by such hazards: 1) chronic stresses of extreme heat; 2) frequent impacts from stormwater flooding; and 3) frequent and acute events of coastal and riverine flooding. Within the CRB Vulnerability Assessment is an evaluation of exposure and consequences of the three hazards, including an evaluation of potential quantified losses due to coastal and riverine flood impacts. Losses considered for the analysis include structure damage, contents and inventory losses, displacement costs, shelter needs, business interruption losses to the local economy, and stress factors on the human population. Additional exposure evaluations for coastal and riverine flooding consider property value (building and land), as well as number and types of buildings and people, as well as known infrastructure, that are within harm's way.

This Appendix includes a description of the approach CRB analysts developed to conduct the exposure and consequence analysis, including detail on the data gathering process and methods used to evaluate exposure to various hazards and the consequences of coastal and riverine flooding. All values within this approach are estimates based on hypothetical and modeled hazard scenarios, and known and unknown data limitations exist. These limitations are described where known. Real impacts of coastal and riverine flooding will differ based on the particulars of the event as it happens. Refer to the **Hazard Data Development Appendix** for more detail on how hazard data was acquired and processed for use in the CRB Vulnerability Assessment. Detailed results of the exposure and consequence analyses are provided in the **Detailed Result Appendix.**

The Appendix is organized as follows:

- **Asset Inventory and Development.** CRB developed a detailed asset inventory to capture exposure of Boston's people, property, economy, and infrastructure to heat and flood hazards, and to examine the expected consequences of coastal and riverine flooding, more specifically. The asset inventory is comprised of two datasets that work together to inform the exposure and consequence analysis: Building Information (attributes and analysis results) and Site-Specific Asset inventory (attributes only). The full asset inventory is comprised of over 130 separate datasets from a variety of sources. Steps required to collect the data and develop the asset inventory are described within this section.
- **Property.** The Property section within the Appendix describes the process CRB Analysts used to consider exposure of Bostonians' homes, businesses, schools, possessions, and more – at risk of impacts from stormwater flooding and coastal and riverine flooding. Refer to this section for

detailed descriptions on an analysis of structure exposure (types of buildings expected to be impacted by flooding), property value exposure (the taxable value of land exposed to flood impacts), infrastructure exposure (assets of particular importance to the City expected to be impacted by flooding), expected structure damage and contents losses, and expected costs of resident and business displacement (refer to Table 1 for detail).

- **People.** A key part of CRB is analyzing how climate-related hazards will impact Boston residents. The People section within the Appendix reviews the methods used to estimate the number of persons exposed or expected to be displaced as the result of an event, the number of people that may require shelter in a coastal or riverine flood event, and expected costs of mental stress and lost productivity due to coastal or riverine flood impacts.
- **Economy.** The Economy section within the Appendix describes the approach CRB analysts used to estimate disruption of business operations and job loss as a result of coastal and riverine flood impacts. Business interruption is quantified through loss of sales and revenues (output).

TABLE 1. LOSSES CONSIDERED FOR COASTAL AND RIVERINE FLOOD IMPACT ASSESSMENT

Impact Category	Loss Category	Losses Considered	Description
Property	Direct Physical Damages to Buildings	• Structure Damage • Content and Inventory Loss	Direct physical damages include the destruction and degradation of buildings as a result of coastal or riverine flooding and are quantifiable as monetary losses based on the expected 2016 replacement cost of impacted assets.
Property	Displacement	• One-time Displacement and Relocation Costs	Displacement and relocation costs are associated with moving a household or a business to a new location and resuming activity in that new location.
People	Stress Factors	• Mental Stress and Anxiety • Lost Productivity	Natural disasters threaten or cause the loss of health, social, and economic resources, which leads to psychological distress. Stress factors are a product of damage to people's homes, and are quantified as treatment costs, as well as lost income to workers.
People	Shelter Needs	• Number of persons and households in need of public shelter	Shelter needs for coastal and riverine flood events are calculated as a function of flood depth and certain social vulnerability factors, such as age and income of the affected population.
Economy	Business Interruption	• Loss of Employment • Output Loss	Business interruption is associated income and output lost to the economy as a result of an event that disrupts the operations of the business, or the removal of a piece of real estate, both rental and sale properties, from the market as a result of disaster impacts.

1.2 Summary of Reporting Format

Loss estimations for people, property, and the economy presented in the CRB Vulnerability Assessment are reported both as one-time costs by event in total and by loss category, and as an annualized value for each sea level rise condition.[1] Annualized values represent the total of the product of single losses expected for each projected sea level rise condition and the chance of occurring in any given year. This method facilitates resiliency planning by allowing for comparison across areas and events, as well as expected losses in each sea level rise scenario.

Annualizing losses is one method used to "normalize" results of an evaluation (or even historical losses) in order to communicate risk. In fact, the definition of *risk* is often communicated as *probability x consequence*; this is exactly how annualized losses are calculated. Annualized losses can be used to compare the impacts of different events across time for mitigation planning purposes, and can even be used to compare the effects of entirely different hazards (so long as a probability of impact and potential costs of such impact can be derived). Expected relocation costs within the City as a result of 9 inches of sea level rise (near term sea level rise scenario) can be used to illustrate this point:

TABLE 2. ANNUALIZATION OF ESTIMATED RELOCATION COSTS FOR THE 9 INCH SEA LEVEL RISE SCENARIO

Event	One-time Event Consequences	Probability (Percent Annual Chance)	Annualized (Probability x Consequence)
10 percent (high probability)	$12,000,000	10 percent	$1,200,000
2 percent	$30,500,000	2 percent	$600,000
1 percent (lower probability)	$35,600,000	1 percent	$400,000
0.1 percent	$155,200,000	0.1 percent	$200,000
Total	*cannot be calculated*	-	$2,400,000

By annualizing the losses of this event, it becomes apparent that the *risk* (probability x consequence) associated with the 10 percent annual chance event is higher than the lowest probability event evaluated, despite the fact that one time event costs for the 10 percent annual chance are expected to

[1]Annualized values consider four of the five frequencies considered in this Vulnerability Assessment, including the 10 percent, 2 percent, 1 percent, and 0.1 percent annual chance flood. Direct damages for each of the flood frequencies for one sea level rise condition were multiplied by their percent chance of occurrence and then added together to yield the annualized value for one sea level rise condition. The annualized values in this report do not consider frequent flood events such as high tides or storms with a chance of occurrence greater than 10 percent.

be significantly lower. This informs the resiliency planner that properties within the 10 percent annual chance flood area should perhaps be prioritized for action prior to those at risk only to lower probability events.[2] Such a decision would need to be made in combination with other factors, such as criticality of a structure to the community.

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[2] Risk prioritization should take into consideration a variety of factors.

2. ASSET INVENTORY AND DEVELOPMENT

CRB analysts developed two sets of data that provide the foundation of the Vulnerability Assessment's exposure and impact analysis: building information, and site-specific asset information. The two datasets were developed separate of each other due to their source origins, to cross-reference information, and identify potential discrepancies. In addition, there is sensitive information in the site-specific asset inventory subject to non-disclosure agreements that warrants independent maintenance and storage, whereas the building information dataset can be freely shared. The exposure analysis related to infrastructure systems and other site-specific assets do not consider assets that were provided under a non-disclosure agreement; evaluation of such elements is described within the Vulnerability Assessment qualitatively and as allowable by agreements made with the individual entities. All structures, however, are included in the consequence analysis for structure damage and contents losses (including any related to site-specific analysis). The Asset Inventory and Development section herein describes the information used to develop the two datasets and any action necessary to reconcile potential inconsistencies.

2.1 Building Information

The building information dataset provides building-level data on existing development in Boston, allowing analysts to reference structure location, type, square footage, building use, and other information pertinent to the Vulnerability Assessment. Building information data developed for the Vulnerability Assessment consists of two datasets: CRB Building Footprints and the CRB General Building Stock. The CRB Building Footprints dataset is a polygon file, and contains limited structure information; the CRB General Building Stock is a point file, with points derived from building footprint centroids, and has more structure information required to complete the exposure and consequence analyses described in the Property, People, and Economy sections below. Refer to Table 6 and Table 7 for a list and short description of attributes associated with each dataset.

Analysts created the CRB Building Footprints dataset first, which is comprised of a variety of sources, developed separate of each other and with varying levels of accuracy. The CRB team recognizes this as a limitation of this Vulnerability Assessment, and recommends future assessments continue to review and expand upon building information data so Boston may have a complete and accurate building dataset. Refer to the **Data Integrity and Fidelity, as well as Quality Assurance and Quality Control Evaluations** section within this report for additional limitations associated with the CRB asset inventory.

TABLE 3. DATASETS USED TO COMPILE BUILDING INFORMATION DATA

Dataset	Analysis Use
City of Boston Building Footprints (2012)	Primary dataset for building footprint and structure type. Includes building height. All footprints within this dataset remain in the CRB Building Footprint dataset.
MassGIS Building Footprints (2011-2012)	Supplement City of Boston Building Footprints with additional structures with footprints greater than 1,000 square feet.[3]
Boston Redevelopment Authority Development Pipeline Data (Spring 2016)	Enhance City of Boston Building Footprints with structures built after 2012 that did not already exist in the City dataset.
Boston Redevelopment Authority New Buildings CAD File (Spring 2016)	Provide building footprints for Development Pipeline data added to the general building stock.
City of Boston Property Tax Assessing Data (Spring 2016)	Source of structure use (PTYPE) and real estate property value attributes.
Bing Aerial Imagery	Used to screen data for current conditions.
Google Aerial Imagery	Used to screen data for current conditions.
Google Street View	Used to screen data for current conditions and estimate building height of buildings added to the primary dataset.
2009 LiDAR Topography	Provide structure grade elevation (refer to the **Building Elevation** section for more detail on why the most recent LiDAR data was not used for the analysis).

[3] MassGIS Building Footprint data does not include structure type; spot evaluation of a number of the buildings less than 1,000 square feet indicated that most of the structures were outbuildings or awnings.

2.1.1 Building Footprints

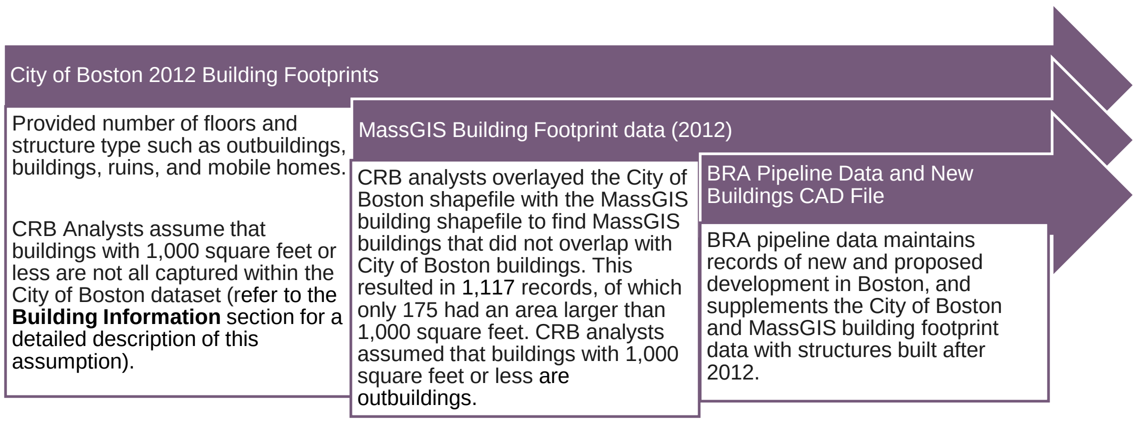

FIGURE 1. CRB BUILDING FOOTPRINT DATA PROCESS OVERVIEW

The primary data source for the CRB Building Footprint data is the City of Boston 2012 Building Footprints, which provided the number of floors and structure type such as buildings, building foundation, building under construction, outbuilding, overhead walkway joining buildings, ruins, and mobile homes. Due to the age of the dataset and discrepancies found upon review of other data sources, the MassGIS Building Footprints Data (2011-2012) and the Boston Redevelopment Authority (BRA) New Buildings CAD file and Development Pipeline Data, supplement the City of Boston 2012 Building Footprint dataset for the CRB Vulnerability Assessment.

Many additional buildings exist in the MassGIS Building Footprint data that are not present in the original City of Boston Building Footprint dataset. To identify potential additional buildings to add to the CRB Building Footprint dataset, CRB analysts overlaid the MassGIS building shapefile with the City buildings shapefile in GIS, and performed a selection analysis to find MassGIS buildings that did not overlap with the City of Boston buildings. This resulted in 1,117 records, of which only 175 had an area larger than 1,000 square feet. MassGIS Building Footprint data does not include structure type; spot evaluation of a number of the buildings less than 1,000 square feet indicated that many of the structures were outbuildings or awnings, rather than adjacent structures or row houses. Due to time constraints, analysts used the results of the spot evaluation to assume that any buildings less than 1,000 square feet may be considered an outbuilding such as a garage or a shed. This assumption may exclude small single-family residential structures that are not captured in the City of Boston Building Footprint dataset from the CRB Building Footprints Dataset. Nevertheless, QAQC of the data revealed that this might be a very limited concern.

CRB analysts conducted additional comparisons between the MassGIS and City of Boston building data to assess the accuracy of the City of Boston building data. A building and parcel analysis was conducted to identify parcels for which the area covered by buildings varied by more than 15 percent between the two datasets. This threshold assumes that differences less than 15 percent were likely to have been due to differences in building footprint for identical buildings, rather than representing additional buildings. Note that the largest changes in building footprint (either gained or lost) were associated with misclassifications of paved areas as buildings in the MassGIS dataset or missed rooftops between higher buildings that the dataset appeared to assume were not buildings. This provides a strong indication that the City of Boston buildings dataset is more accurate and the best data source for the analysis.

The BRA's Development Pipeline Data, which maintains documentation of new and proposed development in Boston, supplemented the City of Boston and MassGIS building footprint data with structures built after 2012. Projects that the Development Pipeline data indicated as complete or under construction as of 2012 were screened for inclusion in the general building stock as "recent additions." CRB analysts compared those records with City of Boston building footprint data, and those with existing records in the footprint data were not added to the CRB Building Footprint data to avoid duplication. Also excluded from the CRB Building Footprint data were pipeline points representing non-building improvements (e.g. parks); the remaining "recent addition" pipeline points were compared to the City of Boston Assessing data. If the Assessing data indicated no assessed value or had no record, analysts considered the property unimproved.[4] Building footprints for properties with assessed values were sourced from the BRA's New Buildings CAD file, or digitized based off aerial imagery. All building footprint parcels were assigned a unique ID, called the CRBID, for ease of identification, cross-referencing, and quality control. Original identification numbers and sources of buildings are maintained in the CRB Building Footprint data to assist the City in identifying original data sources.

[4] Google Street View was used to screen any questionable properties for existing conditions.

2.1.2 Structure Information

Structure Attributes Available in Boston Datasets

- Square Footage
- Number of Stories
- Building elevation
- Building Use
- Real Estate Property Value

In order to assess the potential for structural damage and other impacts related to coastal and riverine flooding, analysts must build upon the building footprint data to understand structure square footage, number of stories, building elevation, real estate market value, building use, and other attributes, some of which must be developed or calculated in the absence of available existing data. This set of structure information is referred to as the general building stock throughout the remainder of this report. When possible, these attributes are sourced from a singular dataset to promote data consistency. Deviations from this approach are detailed below.

Square footage

The City of Boston Building Footprint dataset did not contain structure square footage in its attribute data. Rather than supplement structure square footage data from other datasets, CRB analysts calculated the area of the building footprint polygons using the "Calculate Geometry" tool in ArcGIS. The area of the building footprint is considered the square footage per floor for the remainder of this analysis.

Number of stories

The number of stories for a building is provided in the City's Assessing data; however, Assessing records are based on ownership within a parcel, rather than by building. Thus, there may be multiple records for one building, particularly condominiums, each one reporting a different number of floors. Nevertheless, the City of Boston Building Footprint dataset essentially contains the height of the building (ground level). CRB analysts divided this building height by 10 feet, and rounded to the nearest whole number, to determine the approximate number of floors that would exist within each building. This is a rough, yet necessary, approximation of building height because structure height is not always uniform from foundation to rooftop. [5]

Structures added to the general building stock as a supplement to the City of Boston Building Footprint data that did not have number of stories or structure height information available, were assumed to be

[5] This could lead to some data discrepancies for multi-story structures that change shape as they rise, but the implications of this are expected to be minimal; the consequence analysis mostly considers impacts on the lowest floors of the structure. Nevertheless, square footage for up to ten floors for urban high rise structures is considered due to processes required to use the depth damage functions. Please see **Section 3.4 Structure Damage and Contents Losses** for more on this.

single-story structures if the building area was between 1,000 and 2,000 square feet. CRB analysts used aerial imagery and Google Streetview to estimate building height for polygons with footprints larger than 2,000 square feet, assuming a general floor height of 10 feet. Analysts employed the latter approach to estimate building height for approximately 200 structures. To determine the total structure square footage, analysts multiplied the square footage per floor by the structure's number of stories.

Building elevation

Structure grade elevation is an essential field used to estimate the approximate flood depth within structures for the various flood scenarios evaluated. To determine the structure grade elevation, CRB analysts extracted the average elevation within a structure footprint from the 2009 LiDAR topography dataset. This approach does not identify the presence of basements, although basement information is not necessary for the exposure and consequence analysis (refer to the **Structure Damage and Contents Loss Exposure Analysis** for more detail). More recent LiDAR data exists (2012), but analysts chose to use the 2009 LiDAR dataset to maintain consistency with the data used to develop depth grids for coastal and riverine flooding.

Building use

Various building uses, or occupancies, are affected differently by flood hazard. As such, building use is a critical field to understand potential flood impacts. The Boston Assessing data provides the structure use for each record within a parcel, referred to as a PTYPE; records are based on property use and ownership within a parcel, and are not directly correlated to building footprints. In order to attach an assessing record's PTYPE to a building footprint, three datasets were overlaid in ArcGIS: Boston parcel geometry, Boston Assessing records, and the CRB building footprint dataset (the results of the building footprint analysis and reconciliation described above). CRB analysts used the following approach to assign PTYPEs to a building:

1. Spatially join parcel data to assessing data, so that each assessing record has a parcel ID and each parcel has a group of assessing records. This is important for the case of condominiums and other parcels and structures with multiple assessing records;
2. Spatially join assessing records to building footprints so each structure has a parcel ID and PTYPE

Building footprints that did not have associated assessing records after this process were screened using aerial imagery and Google Streetview to determine property use. Structures with multiple assessing records of different PTYPEs, one of which was residential, were reassigned as mixed-use buildings.

PTYPE Categories

CRB analysts assigned categories to PTYPES to assist in the exposure and consequence analysis. Two category frameworks exist: a detailed category and a quick category used throughout the Vulnerability Assessment to facilitate reporting. Table 4 provides the PTYPE mapping used in the CRB Vulnerability Assessment. The Property Class Descriptions are based on the property classification system used by the Boston Assessing Department;[6] buildings with PTYPES not found on the Boston Assessing Department list were reviewed in GIS and in Google Streetview, and assigned descriptions based on the Massachusetts property type classification codes.[7] All three use categories are retained in the dataset for future adjustment, as needed.

TABLE 4. PTYPE CATEGORIES

PTYPES	Property Class Description	Detailed Category	Quick Category
Multiple Use Property			
10	Condo Multi-Use	Mixed Use	Mixed Use
012	Res /Open Space Use	Mixed Use	Mixed Use
13	Res /Commercial Use	Mixed Use	Mixed Use
19	Res /Exempt Use	Mixed Use	Mixed Use
25	Rc: One Res Unit	Mixed Use	Mixed Use
26	Rc: Two Res Units	Mixed Use	Mixed Use
27	Rc: Three Res Units	Mixed Use	Mixed Use
31	Com /Res Multi-Use	Mixed Use	Mixed Use
Residential Property			
101	Single Fam Dwelling	Residential - 1-3 Family	Residential
102	Residential Condo	Residential - Multifamily	Residential
103	Mobile Home	Residential - 1-3 Family	Residential
104	Two-Fam Dwelling	Residential - 1-3 Family	Residential
105	Three-Fam Dwelling	Residential - 1-3 Family	Residential
106	Res Ancill Improvemt	Residential - Other	Residential
107	Other Residential	Residential - Other	Residential

[6] Boston Assessing Department. Massachusetts Property Classification System Occupancy Codes. [web page] located at: https://www.cityofboston.gov/images_documents/MA_OCCcodes_tcm3-16189.pdf.

[7] Massachusetts Department of Revenue. Property Type Classification Codes. [web page] located at: http://www.mass.gov/dor/docs/dls/bla/classificationcodebook.pdf.

PTYPES	Property Class Description	Detailed Category	Quick Category
108	Condo Parking (Res)	Parking and Storage	Residential
109	Multiple Bldgs/1 Lot	Residential - 1-3 Family	Residential
110	Condo Storage (Res)	Parking and Storage	Parking and Storage
Apartment Property			
111	Apt 4-6 Units	Residential - Multifamily	Residential
112	Apt 7-30 Units	Residential - Multifamily	Residential
113	Apt 31-99 Units	Residential - Multifamily	Residential
114	Apt 100+ Units	Residential - High Occupancy	Residential
115	Co-Op Apartment	Residential - Multifamily	Residential
116	Res Parking Garage	Parking and Storage	Parking and Storage
117	Day Care Use	Child Care Facility	Essential Services
118	Elderly Home	Residential - Clinic	Residential
119	Res Parking Lot	Parking and Storage	Parking and Storage
120	Multi-Use	Mixed Use	Mixed Use
121	Rooming House	Residential - Multifamily	Residential
122	Fraternity House	Residential - Multifamily	Residential
123	Residence Hall	Residential - High Occupancy	Residential
124	Dorms Or Group Housing	Residential - High Occupancy	Residential
125	Subsd Housing S- 8	Residential - Subsidized Housing	Residential
126	Subsd Housing S-231D	Residential - Subsidized Housing	Residential
127	Subsd Housing S-202	Residential - Subsidized Housing	Residential
130	Residential Land	Residential - Other	Residential
131	Res Land (Secondary)	Residential - Other	Residential
132	Res Land (Unusable)	Residential - Other	Residential
140	Child Care Facility	Child Care Facility	Essential Services
150	Apt : Studio	Residential - Multifamily	Residential
151	Apt : 1 Bedroom Unit	Residential - Multifamily	Residential
152	Apt : 2 Bedroom Unit	Residential - Multifamily	Residential
153	Apt : 3 Bedroom Unit	Residential - Multifamily	Residential
154	Apt : 4 Bedroom Unit	Residential - Multifamily	Residential
Commercial Property			

PTYPES	Property Class Description	Detailed Category	Quick Category
300	Hotel	High Occupancy (NonResidential)	Commercial
301	Motel	High Occupancy (NonResidential)	Commercial
302	Inn, Resort, B & B	High Occupancy (NonResidential)	Commercial
303	Priv City Club	High Occupancy (NonResidential)	Commercial
304	Nursing /Conv Home	Residential - Clinic	Residential
305	Hospital: Private /Taxable	Hospital/Medical	Essential Services
306	Laboratory	Hospital/Medical	Essential Services
307	Veterinary Hospital	Hospital/Medical	Essential Services
309	Med Clinic Outpatient	Hospital/Medical	Essential Services
310	Laundry Operation	Commercial - Service Based	Commercial
311	Laundromat /Cleaner	Commercial - Service Based	Commercial
312	Mini-Storage Whse	Parking and Storage	Parking and Storage
313	Lumber Yard Storage	Industrial	Industrial
314	Truck Terminal	Transportation	Transportation
315	Piers / Dock	Transportation	Transportation
316	Warehouse / Distributi	Industrial	Industrial
317	Storage Whse / Garage	Parking and Storage	Parking and Storage
318	Cold Storage Whse	Parking and Storage	Parking and Storage
319	Strip Center /Stores	Commercial - Retail	Commercial
320	Retail /Whsl /Service	Commercial - Retail	Commercial
321	Discount Store	Commercial - Retail	Commercial
322	Department Store / Mal	Commercial - Retail	Commercial
323	Shopping Center	Commercial - Retail	Commercial
324	Supermarket	Food Supply	Food Supply
325	Retail Store Detached	Commercial - Retail	Commercial
326	Restrant /Service	Commercial - Service Based	Commercial
327	Restrant /Lounge	Commercial - Service Based	Commercial
328	Fast Food Restaurant	Commercial - Service Based	Commercial
329	Bar /Tavern /Pub	Commercial - Service Based	Commercial
330	Showroom (Auto)	Commercial - Retail	Commercial
331	Auto Supply /Service	Commercial - Service Based	Commercial

PTYPES	Property Class Description	Detailed Category	Quick Category
332	Repair /Serv Garage	Commercial - Service Based	Commercial
333	Self-Serv Station	Commercial - Service Based	Commercial
334	Service Center / Retail	Commercial - Service Based	Commercial
335	Car Wash: Automatic	Commercial - Service Based	Commercial
336	Com Parking Garage	Parking and Storage	Parking and Storage
337	Parking Lot	Parking and Storage	Parking and Storage
338	Subterranean Garage	Parking and Storage	Parking and Storage
339	Car Wash: Self-Service	Commercial - Service Based	Commercial
340	Office (Attached)	Commercial - Office	Commercial
341	Bank Building	Commercial - Office	Commercial
342	Medical Office	Hospital/Medical	Essential Services
343	Office 1-2 Story	Commercial - Office	Commercial
344	Office 3-9 Story	Commercial - Office	Commercial
345	Office : Class B	Commercial - Office	Commercial
346	Office : Class B+	Commercial - Office	Commercial
347	Office : Class A-	Commercial - Office	Commercial
348	Office Tower: Class A	High Occupancy (NonResidential)	Commercial
350	Postal Service	General Government	General Government
351	Training /Priv Educ	Education	Education
352	Day Care Use (Com Bldg)	Child Care Facility	Essential Services
353	Social Club	Recreational	Recreational
354	Mausoleum	Cultural	Cultural/Religious
355	Funeral Home	Commercial - Service Based	Commercial
356	Comm Condo	Commercial - Service Based	Commercial
357	Retail Condo	Commercial - Retail	Commercial
358	Office Condo	Commercial - Office	Commercial
359	Condo Parking (Com)	Parking and Storage	Parking and Storage
360	Museum, Gallery	Cultural	Cultural/Religious
361	Night Club	Recreational	Recreational
362	Movie Theater	High Occupancy (NonResidential)	Recreational
363	Drive-In Theater	Recreational	Recreational

PTYPES	Property Class Description	Detailed Category	Quick Category
364	Stage Theater	Recreational	Recreational
365	Auditorium/Sport Ctr	High Occupancy (NonResidential)	Recreational
366	Fieldhouse /Track	Recreational	Recreational
367	Race Track	High Occupancy (NonResidential)	Recreational
368	Fairground, Park	Recreational	Recreational
369	Artist Studio	Commercial - Service Based	Commercial
370	Bowling Alley	Recreational	Recreational
371	Arena: Ice Skating	Recreational	Recreational
372	Arena: Roller Skating	Recreational	Recreational
373	Swimming Pool -Enclosed	Recreational	Recreational
374	Health Spa /Club	Commercial - Service Based	Commercial
375	Tennis/ Racquet Club	Recreational	Recreational
376	Gym /Athletic Facility	Recreational	Recreational
377	Recreation Bldg	Recreational	Recreational
378	Private Schools/Tutoring Centers	Education	Education
379	Churches	Religious	Cultural/Religious
380	Golf Course	Recreational	Recreational
381	Tennis Court(S)	Recreational	Recreational
382	Stable, Kennel	Recreational	Recreational
383	Swimming Pool -Outdoor	Recreational	Recreational
384	Boat House / Marina	Industrial	Industrial
385	Taxable Bldg Only	Recreational	Recreational
386	Campground Facility	Recreational	Recreational
387	Pay Parking Lot	Parking and Storage	Parking and Storage
388	Air Rights Property	Transportation	Transportation
389	Bldg: Chap 61 A Land	Agriculture	Agriculture
390	Commercial Land	Commercial - Other	Commercial
391	Com Land (Secondary)	Commercial - Other	Commercial
392	Com Land (Unusable)	Commercial - Other	Commercial
393	Com Underwater Land	Commercial - Other	Commercial
394	Utility Bldg /Shed	Other	Other

PTYPES	Property Class Description	Detailed Category	Quick Category
395	Air Freight Terminal	Transportation	Transportation
396	Hangar: Storage, Maint	Transportation	Transportation
397	Bus / Rail Terminal	Transportation	Transportation
398	Airport Terminal	Transportation	Transportation
399	Com Greenhouse	Commercial - Retail	Commercial
Industrial Property			
400	Old Manufacturing	Industrial	Industrial
401	Old Industrial Whse	Industrial	Industrial
402	Office: Industrial Use	Industrial	Industrial
403	New Manufacturing	Industrial	Industrial
404	Light Mfg / R & D	Industrial	Industrial
405	Industrial Loft	Industrial	Industrial
406	Computer Equip Bldg	Industrial	Industrial
407	Machine Shop (Small)	Industrial	Industrial
408	Newspaper Plant	Industrial	Industrial
410	Mining, Quarrying	Industrial	Industrial
412	Metal Processing	Industrial	Industrial
413	Auto Salvage Yard	Industrial	Industrial
414	Food Process Plant	Food Supply	Food Supply
415	Bottling Plant	Food Supply	Food Supply
416	Cannery	Food Supply	Food Supply
417	Dairy	Agriculture	Agriculture
420	Tanks: Above Ground	Utility - Other	Utility
421	Tanks: Under Ground	Utility - Other	Utility
422	Elec Power Plant	Utility - Electric	Utility
423	Elec Trans R O W	Utility - Electric	Utility
424	Elec Substation	Utility - Electric	Utility
425	Gas Manufactr Plant	Utility - Gas	Utility
426	Gas Pipeline R O W	Utility - Gas	Utility
427	Gas Storage	Utility - Gas	Utility
428	Gas Pressure Station	Utility - Gas	Utility

PTYPES	Property Class Description	Detailed Category	Quick Category
430	Teleph Exchg Station	Telecommunications and IT	Telecommunications and IT
431	Teleph Relay Tower	Telecommunications and IT	Telecommunications and IT
432	Cable T V Facility	Telecommunications and IT	Telecommunications and IT
433	Radio /Tv Trans Facil	Telecommunications and IT	Telecommunications and IT
435	Radio /Tv Studio	Telecommunications and IT	Telecommunications and IT
436	Studio /Remote Contr	Telecommunications and IT	Telecommunications and IT
440	Industrial Land	Industrial	Industrial
441	Ind Land (Secondary)	Industrial	Industrial
442	Ind Land (Unusable)	Industrial	Industrial
445	Railroad Prop	Transportation	Transportation
446	Water /Sewer Utility	Utility - Water and Sewer	Utility
450	Industrial Condo	Industrial	Industrial
465	Com Billboard	Industrial	Industrial
Exempt Ownership			
900	U.S. Government	General Government	General Government
901	Commonwealth Of Mass	General Government	General Government
902	City of Boston	General Government	General Government
903	Bost Redevelop Auth	General Government	General Government
904	Priv School /College	University	Education/University
905	Charitable Organiztn	Cultural	Cultural/Religious
906	Religious Organizatn	Religious	Cultural/Religious
907	121-A Property	Residential - Multifamily	Residential
908	Boston Housing Authority[8]	Residential - Subsidized Housing	Residential
910	Mass Dept Environment Mgmt	General Government	General Government
912	Mass Dept Of Youth Services	General Government	General Government
914	Mass Dept Of Mental Health	General Government	General Government
915	Metro Dist Com (Mdc) Land	General Government	General Government
917	Mass Dept Education (College)	University	Education/University
918	Mass Environment Protection	General Government	General Government
920	Mass Environment Mgmt	General Government	General Government

[8] These assets were visually confirmed using Google Earth and Google Street View, as well as local knowledge.

PTYPES	Property Class Description	Detailed Category	Quick Category
921	Mass Environmt Protection	General Government	General Government
922	Mass Corrections / Police	Essential Services	Essential Services
923	Mass Dept Of Public Health	General Government	General Government
924	Mass Highway Dept	General Government	General Government
925	Metropolitan Dist Com (Mdc)	General Government	General Government
926	Mass Dept Justice /Judiciary	General Government	General Government
927	Mass Dept Education (College)	University	Education/University
928	Mass Div Capital Asset Mgmt	General Government	General Government
929	Mass : Other Property	General Government	General Government
937	Dorms, Student Housing	Residential - High Occupancy	Residential
941	Symphony Hall	Recreational	Recreational
942	College (Academic)	University	Education/University
945	School	Education	Education
947	Recreational School Use	Education	Education
950	Retail Condo: Exempt	Commercial - Retail	Commercial
951	Priv School /College	University	Education/University
952	Priv School /College	University	Education/University
953	Health Center	Hospital/Medical	Essential Services
954	Gov'T Office Bldg	General Government	General Government
955	Harvard Medical	Hospital/Medical	Essential Services
957	City Of Boston	General Government	General Government
958	Rehabilitation Centers	Hospital/Medical	Essential Services
959	Women's Care Centers	Hospital/Medical	Essential Services
960	Office Condo: Exempt	Commercial - Office	Commercial
962	Port Authority Property	Transportation	Transportation
963	Seafood Market	Food Supply	Food Supply
965	Gov'T Office Bldg	General Government	General Government
966	Piers / Dock	Transportation	Transportation
968	School	Education	Education
969	Piers / Dock	Transportation	Transportation
970	Church, Synagogue	Religious	Cultural/Religious

PTYPES	Property Class Description	Detailed Category	Quick Category
971	Rectory, Convent	Religious	Cultural/Religious
972	Correctional Bldg	High Occupancy (NonResidential)	Essential Services
973	Administrative Bldg	General Government	General Government
974	Fire Station	Essential Services	Essential Services
975	Police Station	Essential Services	Essential Services
976	School	Education	Education
977	College (Academic)	University	Education/University
978	Library	Cultural	Cultural/Religious
979	Hospital (Exempt)	Hospital/Medical	Essential Services
980	Water Treatmt Plant	Utility - Water and Sewer	Utility
981	Incineration Plant	Utility - Steam	Utility
982	Armory (Military)	Essential Services	Essential Services
983	Cemetery	Cultural	Cultural/Religious
984	Public Beach	Recreational	Recreational
985	Improved Municipal Or Public Safety, Other City Or Town	Essential Services	Essential Services
986	Local/State Transportation	Transportation	Transportation
987	Public Housing	Residential - Subsidized Housing	Residential
990	Logan Airport	Logan Airport	Transportation
988	Convention Center	Cultural	Cultural/Religious

Property market value (land plus improvements)

Property market value is an important consideration when looking at exposure of buildings to recurrent flooding. Real estate market values can decrease significantly with increased perception of flood risk, which may not only affect the cost of ownership of exposed buildings in the future, but also affect their desirability. The Boston Assessing data contains building and land assessed values; these values are provided per record; as such, there are often multiple assessing records for both parcels and buildings and some records must be summed. Analysts employed the below approach to assign real estate property value (land plus improvements) to building footprints. Assessed value is the valuation placed on a property by a public tax assessor for the purpose of taxation; thus, property value estimates reported in the CRB exposure and consequence analysis are likely a conservative reflection of Boston's property market values. It is important to note that the laws of the State of Massachusetts require that assessing records include full market value.[9] As such, analysts used the market values as is.

1. Spatially join Assessing data to parcel data. Total assessed values are summed by parcel ID to get the total real estate market value present within a parcel; this combines condominium values into a single total value per parcel.
2. Spatially join building data (which has already been joined to the Assessing records) to parcel data. The total square footage (footprint multiplied by number of stories) is calculated per parcel. Each building within a parcel is then assigned the percentage of square footage that it contributes to the building area within a parcel. The total value of the parcel is multiplied by the building's assigned percentage to determine the value of the building. For most buildings, this value is 1, which indicates that most parcels contain only one building.

2.1.3 Data Integrity and Fidelity, as well as Quality Assurance and Quality Control Evaluations

As the general building stock is a compilation of various data sources, CRB analysts performed several quality control reviews to verify data accuracy.

QAQC of Building Polygons

Large buildings with complex rooflines, especially those with varying heights, consist of multiple polygons in the City of Boston building footprint dataset. Each building polygon is used in the exposure and consequence analysis, and while the square footage and height of each polygon would not skew the results of the quantified consequence analysis, the extra polygons may result in an overestimate of the number of buildings reported as exposed to hazards. To avoid overestimating the number of buildings exposed to coastal and riverine flooding, CRB analysts conducted a quality control review of buildings within the flood extent of the 0.1 percent annual chance event with 36 inches of sea level rise that were over 10,000 square feet and adjacent to others, and had identical PTYPEs. The focus of the review was further limited to screen structures within the General Government, Essential Services,

[9] According to Massachusetts General Laws, Chapter 59, Section 38, "*The Assessing Department is statutorily required to assess all property at its full and fair cash value as of January 1 of each year (Massachusetts General Laws, Chapter 59, Section 38). The assessed value for the Fiscal Year 2016 tax bill represents the fair cash value of property as of January 1, 2015."* See *City of Boston Property Tax Facts and Figures: Fiscal Year 2016* for more information, located at:
https://www.cityofboston.gov/images_documents/FY2016%20Facts%20%26%20Figures_tcm3-52871.pdf

Industrial, and Hospital/Medical building categories, as CRB analysts assumed that these types of uses are likely to be located within large buildings with complex rooflines. This limited the review to approximately 400 structures. Structures that met the aforementioned criteria were provided modified CRBIDs, and the parts were dissolved into a single polygon. A representative number of floors was determined based on the following calculation:

$$[Sum\ of\ (Footprint\ of\ each\ Polygon * Number\ of\ Floors\ of\ each\ Polygon)]/$$
$$[Sum\ of\ Footprint\ Area] = Number\ of\ Floors$$

Once the buildings were dissolved, the modified building dataset was re-merged with the general building stock based on the CRBBldgID.

QAQC of Elevations and PTYPEs

CRB analysts reviewed elevations of a sample set of structures (approximately 150 structures) to ensure accuracy of average structure grade elevations pulled from LiDAR and accuracy of building occupancy labels. The evaluation was performed using Google Earth and Streetview. CRB analysts conducted the review by cross-referencing the ground elevation posted by Google Earth at a site, and used Streetview to gauge the height of the structure's first floor off the ground. Due to differences in the datum of the two elevation datasets, and to account for rounding, elevation differences that were less than two feet were considered appropriate. This review also allowed analysts to confirm PTYPE assignments for a sample of structures. Elevations and PTYPEs were manually adjusted in the general building stock as needed.

CRB analysts performed a running quality control evaluation of elevations and PTYPEs as described above throughout the exposure and consequence analysis. Each neighborhood's top 15 structures with the highest estimated annualized structure damage and contents loss values were reviewed to ensure accuracy. As changes were made, any structures that moved into the top 15 were additionally reviewed. This resulted in a manual review of the occupancies of several hundred structures. More on this process is described within the **Structure Damage and Contents Loss Consequence Analysis** section below.

2.1.4 Building Information Assumptions and Limitations

The CRB team recognizes the approach to construct the full general building stock is not without limitations. Assumptions made in developing the general building stock and associated data limitations include:

- When adding MassGIS Building Footprint data to the City of Boston Building Footprint data, CRB analysts assumed that any new structures less than 1,000 square feet to be an outbuilding such as a garage or shed and were not added (though no structures less than 1,000 square feet were removed from the City of Boston dataset). A threshold had to be set due to the absence of occupancy data in this supplemental dataset, and the time that would be required to manually review and confirm the uses and occupancies of all structures. This structure size was selected and confirmed through an analysis of a sample of structures using Google Streetview. As MassGIS data did not include building height, structures from this dataset between 1,000 and 2,000 square feet were assumed to be single-story buildings. This is based on the fact that the average footprint for buildings with two stories was found to be around 2,000 square feet (determined by the City of Boston Building Footprint data), as confirmed through Google Streetview using a sample of structures. CRB analysts used aerial imagery and Google Streetview to estimate building height for polygons with footprints larger than 2,000 square feet, assuming a floor height of 10 feet.
- Many residences in Boston are split-level structures, and have living space that sits below grade. The approach to estimate structure grade elevation takes an average of the highest and lowest grade elevation within the footprint of the building. Thus, many structures that are split-level or have basements will have conservatively low damage results in the consequence analysis.
- Assessing records are assumed accurate and up to date. Buildings that had multiple, and divergent, assessing records with various PTYPEs, one of which was residential, assigned to its footprint were reassigned PTYPEs to indicate the structure is mixed-use. Any structures with improperly assigned PTYPES identified through the quality control review were manually modified in the general building stock.
- Due to the number of buildings and the number of structure characteristics and occupancy types within the CRB general building stock dataset, as well as available time and budget, CRB analysts were unable to QAQC all data. As such, analysts prioritized a review of structures within the 0.1 percent annual chance inundation area for 36 inches of sea level rise, which is the furthest extent of the CRB study area. Therefore, the fidelity and integrity of structure information outside of that flood extent has not been verified, and must be considered when performing future analyses, as well as when considering results of the stormwater exposure analysis.[10] Furthermore, QAQC of the CRB general building stock within the 0.1 percent annual chance flood extents with 36 inches of sea level rise prioritized structures with the largest building footprints, due to the

[10] Site-specific assets found to be exposed to stormwater flooding were also reviewed for accuracy; however, this review was limited due to the number of site-specific assets exposed.

potential for such large structures to dramatically affect overall results. Due to the scale of corrections that were required, CRB analysts assume that errors still exist within the general building stock, especially for smaller structures and those outside of the CRB Vulnerability Assessment coastal and riverine flooding study area.

2.2 Site-Specific Asset Information

CRB analysts gathered site-specific information for infrastructure assets and systems to assess exposure to hazards. Infrastructure assets and systems considered range from critical facilities, such as water treatment facilities and generating plants, to transportation infrastructure, to essential facilities such as hospitals and emergency operations centers, to public facilities such as schools and civic structures. The CRB site-specific asset information data collection process consisted of two major efforts: first, gathering all available and appropriate public data, and second, collecting information from individual agencies and organizations, as well as the IAG. CRB analysts cross-referenced site-specific information received with the general building stock, to serve as a secondary quality control review for structure use, and modified information in the general building stock as appropriate.

2.2.1 Asset Data Collection

CRB analysts gathered publicly available data from a variety of sources in ArcGIS format, most notably BostonMaps,[11] MassDOT,[12] and MassGIS.[13] CRB partners, including Sasaki, Boston Department of Innovation and Technology (DoIT), the Boston Redevelopment Authority (BRA), and the Boston Regional Intelligence Center (BRIC), also submitted robust datasets for review and inclusion in the CRB asset inventory. CRB analysts compiled all polygon files into a geodatabase, and created six general categories for which to organize the data: environmental systems, transportation systems, utility systems,[14] public facilities, vulnerable populations, health and safety, education, and other. Analysts compiled point data into one shapefile using attributes presented in Table 8, for which certain attributes or sources may be queried. Data received from public sources and CRB partners formed the basis of the site-specific asset inventory. A total list of site-specific data gathered and data sources is provided in Table 5.

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11 http://boston.maps.arcgis.com/home/index.html

12 http://www.massdot.state.ma.us/planning/Main/MapsDataandReports/Data/GISData.aspx

13 http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/layerlist.html

14 Utility systems include water and wastewater and power and gas systems.

To collect information from the IAG, analysts asked members to complete an asset inventory template in Microsoft excel format, and requested any GIS data files applicable to the data request. The template is intended to collect the locations of important assets that are owned or maintained by IAG members, in addition to site-specific information that would allow CRB analysts to evaluate asset vulnerabilities to flood risk and other hazards during future evaluation refinements. Table 8 provides specific attributes requested in the asset inventory template.

Many agencies submitted existing datasets for CRB analysts to pull out necessary information and populate the asset inventory template. Due to privacy and security concerns, utilities and service companies often opted to conduct exposure and consequence analyses on their own, following guidance and using hazard data provided by CRB, and share the results in a qualitative manner with the CRB team. Analysts processed data submitted by IAG members in a manner similar to that described for the public and CRB partner datasets, and built upon the inventory developed for public and CRB partner data.

TABLE 5. DATA COLLECTED[15]

Dataset	Source	Dataset and Category
Airports	MassDOT	Point - Transportation
All Bridges	IAG - OEM	Point - Transportation
Aqueducts	MassGIS	Point - Utility
Areas of Critical Environment Concern	MassGIS	Polygon - Environmental Systems
Article 80 Buildings	IAG - BRA	Point - Other
Bike Lanes and Paths	MassDOT	Polyline - Transportation
Boston City Boundary	OpenData	Polyline - Other
Boston Public Schools	IAG - BPS	Point - Public Facilities
Boston Public Schools	BRA Article 80 Pipeline	Point - Public Facilities
Boston Redevelopment Authority Facilities	Assessor Data	Point - Other
Boston University	Assessor Data	Point - Education
Boston University	BRA Article 80 Pipeline	Point - Education
Bus Routes – MBTA	MassGIS - MBTA	Polyline - Transportation
Bus Stops – MBTA	MassGIS - MBTA	Point - Transportation
BWSC Facilities	Assessor Data	Point - Utilities
BWSC Facilities	BRA Article 80 Pipeline	Point - Utilities

[15] Does not include a list of data collected under Non-Disclosure Agreements.

Dataset	Source	Dataset and Category
BWSC Offices	IAG - BWSC	Point - Utilities
Census Block Groups	MassGIS	Polygon - Other
Census Blocks	MassGIS	Polygon - Other
Census Tracts	MassGIS	Polygon - Other
Central Artery and Tunnel System Facilities	MassDOT	Point - Transportation
Child Care Centers	IAG - OEM	Point - Vulnerable Populations
Colleges and Universities	MassGIS	Point – Education
Colleges and Universities	Assessor Data	Point – Education
Colleges and Universities	BRA Article 80 Pipeline	Point – Education
Community Centers - BCYF	IAG - DoIT - OEM	Point - Health and Safety
Community Health Centers	MassGIS	Point - Health and Safety
Community Health Centers	Assessor Data	Point - Health and Safety
Community Health Centers	BRA Article 80 Pipeline	Point - Health and Safety
Corner Stores	Sasaki	Point - Other
Cultural Institutions	IAG - DoIT - OEM	Point - Other
Dams	MassGIS	Point - Utilities
Department of Conservation and Recreation Facilities	Assessor Data	Point - Environmental Systems
Department of Public Utilities Office	IAG - DPU	Point - Other
Department of Public Works Facilities	Assessor Data	Point - Other
Drainage - Major Basins	MassGIS	Polygon - Environmental Systems
Drainage - Mega Basins	MassGIS	Polygon - Environmental Systems
Drainage - Sub Basins	MassGIS	Polygon - Environmental Systems
Elderly Services	Assessor Data	Point - Vulnerable Populations
Elderly Services - General	IAG - DoIT - OEM	Point - Vulnerable Populations
Elderly Services - Medical	IAG - DoIT - OEM	Point - Vulnerable Populations
Elderly Services - Private Housing	IAG - DoIT - OEM	Point - Vulnerable Populations
Elderly Services - Public Housing	IAG - DoIT - OEM	Point - Vulnerable Populations
Emergency Operations Center Stations	IAG - DoIT - OEM	Point - Health and Safety
Emergency Preparedness Regional Coalitions	MassGIS	Polygon - Health and Safety

Dataset	Source	Dataset and Category
Emergency Preparedness Regions	MassGIS	Polygon - Health and Safety
EMS Districts	DoIT - PSS	Polygon - Health and Safety
EMS Regions	MassGIS	Polygon - Health and Safety
EMS Sites	IAG - DoIT - OEM	Point - Health and Safety
Environmental Justice Communities	MassGIS	Polygon - Vulnerable Populations
Evacuation Routes	BostonMaps	Polyline - Transportation
Farmers' Markets	MassGIS	Point - Other
Ferry Routes	MassDOT	Polyline - Transportation
Fire Districts	OpenData	Polygon - Health and Safety
Fire Response Zones	DoIT - BFD	Polygon - Health and Safety
Fire Sectors	DoIT - BFD	Polygon - Health and Safety
Fire Stations	MassGIS	Point - Health and Safety
Fire Stations	Assessor Data	Point - Health and Safety
Fire Subdistricts	DoIT - BFD	Polygon - Health and Safety
Food Pantries	Sasaki	Point - Vulnerable Populations
Groundwater Conservation Overlay Districts	OpenData	Polygon - Utilities
Harbor Island Facilities	IAG - NPS	Point - Environmental Systems
Harvard	Assessor Data	Point – Educational
Harvard	BRA Article 80 Pipeline	Point – Educational
Hazardous/Abandoned Buildings	IAG - OEM	Point - Environmental Systems
Historic Buildings - MHC	IAG - BLC	Point - Other
Historic District Centroids	IAG - BLC	Point - Other
Historic Landmarks	IAG - BLC	Point - Other
Hospitals	MassGIS	Point - Health and Safety
Hospitals	Assessor Data	Point - Health and Safety
Hospitals	BRA Article 80 Pipeline	Point - Health and Safety
Impervious Surfaces	OpenData	Polygon - Other
Libraries	MassGIS	Point - Other
Libraries	Assessor Data	Point - Other
Libraries	IAG - DoIT - OEM	Point - Other
Light Rail Bridges	IAG - OEM	Point - Transportation
Lighthouses	MassGIS	Point - Other

Dataset	Source	Dataset and Category
Long Term Care Residences	MassGIS	Point - Health and Safety
Long Term Care Residences	Assessor Data	Point - Health and Safety
Major Roads	MassGIS	Polyline - Transportation
Major Routes	MassGIS	Polyline - Transportation
Major Routes	MassDOT	Polyline - Transportation
Major Watersheds	MassGIS	Polygon - Environmental Systems
MassDEP Major Facilities	MassGIS	Point - Environmental Systems
MassDOT Facilities	Assessor Data	Point - Transportation
MassPort Facilities	Assessor Data	Point - Transportation
MassPort Facilities	BRA Article 80 Pipeline	Point - Transportation
MBTA Facilities	Assessor Data	Point - Transportation
MBTA Facilities	BRA Article 80 Pipeline	Point - Transportation
Medical Academic and Scientific Community (MASCO) Member	IAG - MASCO	Point - Health and Safety
MWRA Facilities	Assessor Data	Point - Utilities
National Grid Facilities	Assessor Data	Point - Utilities
National Park Services Facilities	IAG - NPS	Point - Environmental Systems
Neighborhood Emergency Centers	DoIT - MIS	Point - Health and Safety
Neighborhood Emergency Shelters	IAG - DoIT - OEM	Point - Health and Safety
Nursing Homes	IAG - DoIT - OEM	Point - Health and Safety
Oil and/or Hazardous Material Sites with Activity and Use Limitations (AUL)	MassGIS - MassDEP	Point - Environmental Systems
Parks and Open Spaces	IAG - BPRD	Polygon - Environmental Systems
Parks and Recreation Facilities	Assessor Data	Point - Environmental Systems
Partners HealthCare	Assessor Data	Point - Health and Safety
Partners HealthCare	BRA Article 80 Pipeline	Point - Health and Safety
Police Districts	OpenData	Polygon - Health and Safety
Police Facilities	Assessor Data	Point - Health and Safety
Police Facilities	BRA Article 80 Pipeline	Point - Health and Safety
Police Precincts	DoIT - BPD	Polygon - Health and Safety
Police Reporting Areas	DoIT - BPD	Polygon - Health and Safety
Police Sectors	DoIT - BPD	Polygon - Health and Safety

Dataset	Source	Dataset and Category
Police Stations	MassGIS - BRIC	Point - Health and Safety
Police Subsectors	DoIT - BPD	Polygon - Health and Safety
Ponds and Lakes	MassGIS - USGS	Polygon - Environmental Systems
Ponds and Lakes	MassGIS - MassDEP	Polygon - Environmental Systems
Prisons	MassGIS	Point - Vulnerable Populations
Prisons	Assessor Data	Point - Vulnerable Populations
Protected and Recreational Open Space	MassGIS	Polygon - Environmental Systems
Public Housing	Assessor Data	Point - Vulnerable Populations
Public Housing	BRA Article 80 Pipeline	Point - Vulnerable Populations
Public Housing	IAG - BHA	Point - Vulnerable Populations
Public Pools	MassGIS - DCR	Point - Other
Public School Districts	MassGIS - BPS	Polygon – Educational
Public School Facilities	DoIT - BPS	Polygon – Educational
Pump Stations	IAG - MWRA	Point - Utilities
Pump Stations and Headworks	IAG - MWRA	Point - Utilities
Rail – All	MassGIS	Polyline - Transportation
Rail - Commuter Lines	MassGIS	Polyline - Transportation
Rail - Rapid Transit - MBTA	MassGIS - MBTA	Polyline - Transportation
Railroad Bridges	IAG - OEM	Point - Transportation
Railroads	MassDOT	Polyline - Transportation
Rapid Transit Stations - MBTA	MassGIS - MBTA	Point -Transportation
Religious Institutions	Assessor Data	Point - Other
Religious Institutions	IAG - DoIT - OEM	Point - Other
Religious Institutions	BRA Article 80 Pipeline	Point - Other
Road Bridges	IAG - OEM	Point - Transportation
Roads	MassGIS - Census	Polyline - Transportation
Roads	MassGIS	Polyline - Transportation
Roads	MassDOT	Polyline - Transportation
Roads	MassDOT	Polyline - Transportation
Roads	MassDOT	Polyline - Transportation

Dataset	Source	Dataset and Category
Schools	MassGIS - BPS	Point - Educational
Seaports	MassDOT	Point - Transportation
Sidewalks	OpenData	Polyline - Transportation
Soil Survey	MassGIS - NRCS	Polygon - Environmental Systems
Streams and Rivers	MassGIS - USGS	Polyline - Environmental Systems
Streams and Rivers	MassGIS - MassDEP	Polyline - Environmental Systems
Tier II Sites	Boston Fire Dep.	Point – Other
Town and City Halls	MassGIS	Point - Public Facilities
Traffic Count Locations	MassDOT	Point - Transportation
Train Stations	MassGIS	Point - Transportation
Train Stations	MassDOT	Point - Transportation
Transit Terminals	MassDOT	Point - Transportation
Transmission Lines	MassGIS	Polyline - Utilities
Trees	OpenData	Point - Environmental Systems
Trustees of Public Land Facilities	Assessor Data	Point - Other
Tunnels	DoIT - MIS	Polyline - Transportation
Urban Boundaries	MassDOT	Polygon - Other
Verizon	Assessor Data	Point - Other
Water Taxi Stops	MassDOT	Point - Transportation
Water/Sewer Service Areas	MassGIS - MWRA	Polygon - Utilities
Wetland Change Areas	MassGIS - MassDEP	Polygon - Environmental Systems
Wetlands	MassGIS - MassDEP	Polygon - Environmental Systems
Zoning Districts	OpenData	Polygon - Other

2.2.2 Asset Data Reconciliation

When the initial compilation of public data and submitted IAG information was complete, CRB analysts used Boston Assessing data to gather additional assets owned by IAG members (as point data) that may not have been captured within other datasets, and to fill in data gaps existing in the asset template. Due to the number of assets acquired from public datasets, IAG members, and Boston assessing information, analysts focused on reconciling assets located within the flood extent for the 0.1 percent annual chance event with 36 inches of sea level rise; the largest coastal and riverine flood extents considered within the Vulnerability Assessment. A number of site-specific assets exposed to stormwater flooding were also reconciled during the stormwater exposure analysis. Duplicates were removed from the dataset after ensuring that all relevant information for an asset was retained. Then, each IAG member was presented with data relevant to their organization for review to confirm the accuracy and reliability of asset data. IAG members were given multiple opportunities to confirm that the data pulled was correct: at a workshop held on April 12^{th} to present the status of data collection, and in individual follow up conversations and through email correspondence with each participant. The response rate of the data review was limited. As such, and in an effort to limit potentially over-estimating exposure of important infrastructure assets, data gathered from the Assessing data that IAG members did not confirm as special assets or that analysts could not confirm through an aerial analysis were not included in the CRB site-specific asset inventory exposure analysis. These assets were, however, included in the structure exposure and consequence analysis according to the data available in the assessing records. In order to facilitate completion of the inventory for future evaluations, this unconfirmed data has been included in the site-specific asset inventory, listed as “unconfirmed” in the asset attributes.

Once reconciliation was complete, CRB analysts compiled all site-specific asset data provided in point files into a single standardized shapefile, with attributes as listed in Table 8. This template was then joined with Boston Assessing data based on spatial location to determine the parcel ID, approximate date built, approximate date of last significant renovation, and assessed property value (land and improvements).[16]

2.2.3 Asset Data Assumptions and Limitations

- Similar to the building stock, due to the amount of site-specific asset information collected throughout Boston coupled with budget and schedule constraints, CRB analysts prioritized assets for QAQC located within the 0.1 percent chance inundation area for 36 inches of sea level rise, and prioritized certain categories of assets as well. Assets characterized as critical and essential facilities, including hospitals, emergency medical services, emergency shelters, water and wastewater assets, transportation, and power assets were prioritized to ensure that the building footprint, general building stock data, and site-specific asset information were coordinated. Therefore, the fidelity and integrity of site-specific asset information for non-prioritized assets

[16] Assessed property value included in the general building stock likely varies from that pulled for site-specific asset data, due to different approaches followed to assign property value to a structure or asset. The exposure and consequence analyses utilize the general building stock property values; site-specific property values are for reference only and have not been confirmed by IAG members.

must be considered when performing future analyses. This likely also results in duplicate records for assets that did not meet any of the aforementioned criteria to reconcile IAG-submitted information and assessing information.

- Due to privacy and security concerns, many privately owned utilities and service agencies conducted exposure and consequence analyses internally, and shared qualitative results with the CRB team. These results are discussed within the CRB Vulnerability Assessment, but are not incorporated within the asset inventory. See the **Infrastructure Exposure Analysis** section for more on this.
- Assessing data pulled by the CRB team that was not confirmed by an IAG member as a relevant asset is not included in the final asset inventory exposure analysis for this assessment. Nevertheless, the data is included in the inventory, listed as "unconfirmed", and any assets identified as structures have been included in the structure exposure and consequence analyses.
- It is recommended that future analyses continue to refine the asset inventory by continuing to evaluate unconfirmed IAG-related assessing data, and to continue to reconcile building footprint, general building stock, and site-specific asset data. Ultimately, the data may be used in a more efficient manner by eventually merging the datasets together. Nevertheless, security concerns will need to be evaluated and the full-reconciled dataset may not be allowable for sharing due to non-disclosure agreements and other security or privacy considerations. CRB analysts did not merge the data for this reason, as well as the need for further QAQC and continued coordination with IAG members.

2.3 Asset Inventory Attributes

Table 6 through Table 8 below provide a crosswalk of the attributes contributed by the CRB Building Footprint Data, CRB General Building Stock, and the Site-Specific Asset Inventory datasets, respectively.

TABLE 6. CRB BUILDING FOOTPRINT DATA ATTRIBUTES AND DESCRIPTION

Attribute	Field Name	Description
CRB_BLDGID	CRB_BLDGID	Building ID developed by CRB analysts to facilitate data management and QAQC.
Original ID	BUILDING_I	Original footprint ID from the source dataset.
Source	IEL_TYPE	Source of the footprint polygon.
Latitude	Latitude	Reference point of the building centroid.

Attribute	Field Name	Description
Longitude	Longitude	Reference point of the building centroid.
PTYPE	PTYPE	Building use.
Footprint Area	Shape_Area	The square footage of the building footprint.
Number of Stories	NumFloors	Expected number of stories within the building, based on height.

TABLE 7. CRB GENERAL BUILDING STOCK ATTRIBUTES AND DESCRIPTION

Attribute	Field Name	Description
CRB ID	CRB_BLDGID	Building ID developed by CRB analysts to facilitate data management and QAQC.
Latitude	Latitude	Reference point of the building centroid.
Longitude	Longitude	Reference point of the building centroid.
Number of Stories	NumFloors	Expected number of stories within the building, based on height.
PTYPE	PTYPE	Building use.
Building Elevation	LiDAR09_ft2	Sourced from 2009 LiDAR.
Total Structure Square Footage	Total_Structure_SF	Total area of the structure. Result of footprint area multiplied by the number of stories.
Footprint Area	Bldg_footprint	The square footage of the building footprint.
Square Footage Analysis	SF_Analysis	The square footage of the structure to be analyzed for flood impacts based on the requirements of the specific depth-damage function for the structure use and other characteristics. See the **Structure Damage and Contents Loss Exposure Analysis** section for more on the origins of the square footage analysis.
Mixed Use Commercial SF Analysis	MixedUseCOM_SF_Analysis	Portion of the Square Footage Analysis within mixed-use structures that is assumed to be non-residential space.
Total Commercial SF Analysis	TotalComSFAnalysis	Portion of the Square Footage Analysis in a non-residential or mixed-use building that is assumed commercial space.
Mixed Use Residential SF Analysis	MixedUseRES_SF_Analysis	Portion of the Square Footage Analysis within mixed-use structures that is assumed residential space.
Residential SF Analysis	ResidentialSFAnalysis	Portion of the Square Footage Analysis in a residential or mixed-use building that is assumed commercial space.
Total Residential SF	TotalResSFAnalysis	The total square footage of residential space in the building, regardless of flood impact exposure (different from the Square Footage Analysis).
Occupancy Map	Occupancy_Map2	Results from an analysis of the PTYPE and number of stories used to determine appropriate depth-damage functions. See the

Attribute	Field Name	Description
		Structure Damage and Contents Loss Exposure Analysis section for more information.
Hazus Code	HazusCode	Hazus occupancy class code assigned to the structure PTYPE. See the **Structure Damage and Contents Loss Exposure Analysis** section for more information.
DDF Category	DDF_Cat	Depth-damage function category. See the **Structure Damage and Contents Loss Exposure Analysis** section for more information.
Category	Category	CRB building category based on occupancy use.
Quick Category	QuickCategory	CRB building category that aggregates Categories into more broad groups to facilitate reporting of results.
Commercial	Commercial	Notes 1 if the structure is non-residential.
Residential	Residential	Notes 1 if the structure is residential.
Mixed Use	MixedUse	Notes 1 if the structure is mixed use.
DDF ID	DDF_ID	Identification number of the DDF used for the structure; informs the square footage analysis.
GEOID	GEOID10	Census tract that the structure is located in.
Percent Population	Percent_Population	Share of the population within the census tract that may reside in the building; based on amount of residential square footage in the structure and total amount of residential square footage throughout the census tract.
Population	Population	Census tract total population multiplied by the Percent Population to estimate persons that may be living with the building.
Households	Households	Number of households expected to reside in the structure, based on average household size from 2014 ACS 5-year estimates.
Facility Name	FacilityName	Placeholder for name of the asset when the general building stock is merged with site-specific asset information, if applicable.
10 Year, 50 Year, 100 Year, 500 Year AOB Losses	AOBLosses_10Year/ AOBLosses_50Year/ AOBLosses_100Year/ AOBLosses_500Year	Placeholder field for loss of function consequences to be calculated in future evaluations, if applicable.
BRV Analysis	BRV_Analysis	Building replacement value is calculated by multiplying the square footage analysis (not the square footage of the entire structure) by the building replacement value per square foot, and is based on occupancy type. If the structure is mixed use, the first two floors are assigned a non-residential building replacement value.
Alternative BRV Analysis	AltBRV_Analysis	If the structure is mixed use, the remaining floors within the square footage analysis (not the square footage of the entire structure) are assigned a residential building replacement value.
BRV	BRV	Summed BRV Analysis and Alternative BRV Analysis.

Attribute	Field Name	Description
CRV	CRV	Contents replacement value is calculated by applying the CSRV to the BRV analysis. If the structure is mixed use, the first two floors are assigned a non-residential CSRV.
Alt CRV Analysis	AltCRV_Analysis	If the structure is mixed use, the remaining floors within the square footage analysis are assigned a residential CSRV.
Total CRV	TotalCRV	Summed CRV Analysis and Alternative CRV Analysis
1-Time Disruption Cost	One_TimeDisruptionCost	Expected cost to relocate based on the square footage analysis (not the square footage of the entire structure) and occupancy type. If the structure is mixed use, the first two floors are assigned a non-residential disruption cost.
Alternative 1-Time Disruption Cost	Alt_1_TimeDisruptionCost	If the structure is mixed use, the remaining floors within the square footage analysis are assigned a residential disruption cost.
HZ Percent Owner Occupied	HZ_PercentOwnerOccupied	Percent owner-occupancy for non-residential structures, sourced from Hazus.
Residential Percent Owner Occupied	RES_PercentOwnerOccupied	Percent owner-occupancy for residential structures, sourced from American Community Survey 2014 Data.
Rent per Day	Rent_per_Day	Approximate rental rates per day for the structure based on occupancy type. If the structure is mixed use, the first two floors are assigned a non-residential rental rate. See the **Displacement Consequence Analysis** section for more information for origin of rent per day values.
Alternative Rent/Day	AltRent_per_Day	If the structure is mixed use, the remaining floors within the square footage analysis is assigned a residential rental rate.
Total Assessed Value	AssessedValue_Total	The total assessed value of the building (land plus improvements).

TABLE 8. SITE-SPECIFIC ASSET INVENTORY TEMPLATE ATTRIBUTES AND DESCRIPTION

Attribute	Field Name	Instructions to Complete (for IAG Members) and Further Description
Asset ID	AssetID	Enter here an identifier which will allow for information to be correlated between data sets that are being provided, such as GIS data.
Facility Type*	Facility_Type	Choose from the drop-down list a facility type that best represents your asset. This is meant to be general in nature and will be used as the primary classification for the asset type.
Facility Description*	Facility_Description	Further describe your asset in more detail than the Facility Type.

Attribute	Field Name	Instructions to Complete (for IAG Members) and Further Description
Facility Location*	Facility_Street_Address	List the address of the facility, including the zip code.
Longitude/Latitude*	Longitude/Latitude	Longitude and latitude of asset; not required if GIS data are provided.
Acreage of Managed Outdoor Space	Outdoor_Space_Area/ Outdoor_Space_Units	Provide acreage of managed outdoor space for recreational or social uses, if applicable.
Service Area, Population (#), or Population Description*	Service_Area_Description	Define the extent of the area for which the asset provides a service, the service population #, or describe the service population. Please indicate units provided (e.g., square miles) or specific jurisdictions / census blocks, or a specific target population (i.e., elderly, homeless, etc.) if available. Please feel free to attach a map to this response, if available.
Capacity (#) - Please include units*	Capacity_Service_Population	List the population capacity (i.e., beds) and/or the maximum extent to which the asset may operate in numbers. Please provide units.
Annual Operating Budget*	Annual_Operating_Budget	Provide your agency's budget to maintain operations of this particular asset. An estimate is acceptable.
Critical Flood Elevation, or Depth Above Grade	Critical_Flood_Depth/ Critical_Flood_Depth_Units	Most assets are considered vulnerable at the elevation at which water will touch the facility (this may be grade or first floor elevation). For public assets, the elevation of most concern is that which may result in a suspension or loss of service to that asset. Provide the critical flood elevation, if available, or the flood depth above grade at which the asset is expected to lose service as a result of floodwater.
Vertical Reference Datum	Vertical_Reference_Datum	Provide the vertical reference (datum) for the critical flood elevation; enter "n/a" (not applicable) if flood depth above grade is provided.
Criticality to Operations*	Criticality	Rank the asset's criticality to your agency's operations between 1 and 5; 5 being the most critical, 1 being asset is less necessary because of system redundancies or failure impact is not severe
Known Interdependencies - Upstream	Cascading_Impacts_Upstream	What critical assets, services, or infrastructure is this facility reliant upon? (i.e., specific power station - if unknown, identify provider)
Known Interdependencies - Downstream	Cascading_Impacts_Downstream	In the case of loss of this asset, what other impacts can be expected? For example, does the power

Attribute	Field Name	Instructions to Complete (for IAG Members) and Further Description
		supply service a pumping station that services a hospital?
Emergency Plans in Place	Emergency_Plans_in_Place	List known active emergency plans for the asset that could potentially limit loss as a result of a flood event (i.e., Emergency Action Plan (EAP), Emergency Operations Plan (EOP), service MOUs)
Age of Asset* or Date of Last Significant Renovation*	Date_Built/ Date_of_Last_Renovation/ Age_of_Asset	List the age of the asset, and the year that it last received major renovations, if available.
Estimated Replacement Value*	Replacement_Value	Provide the estimated cost that would be required to replace the asset new with comparable design and function.
Number of Personnel*	Number_of_Personnel	If the facility operates as an employer, provide the current number of employees. If the facility is a cultural asset or attracts tourism, provide the number of tourists that visit each year.
Animals Housed	Animals_Housed	Indicate whether live animals are housed at the facility (yes or no)
Distance to Alternate Facility	Alternate_Facility/ Distance_to_Alternate_Facility/ Distance_to_Alternate_Facility_Units	Provide the name of, and the distance to, the closest similar asset that could be used by the service population. This alternate facility does not have to be owned by your agency. Only applicable to essential facilities, such as hospital, police, fire, EMS.
Historical Loss*	Historical_Loss	Indicate "Yes", "No", or "Unknown" if the facility or asset has been impacted by a natural hazard in the past. This can be interpreted as physical impacts or service interruption, and may be due to any natural hazard, such as flood, high temperature, snow storm, etc.
Historical Loss Event Date	-	List the date, or name of the hazard event, of which the facility was affected. If one facility has incurred impacts on multiple occasions, please create a new record for each event.
Type of Loss Event	-	Please indicate the event that led to the loss. For example, coastal flooding, riverine flooding, inadequate drainage, wind event, high temperature, etc.).
Flood Depth Above Grade	-	Provide the depth of the water above grade for the event date.
Loss Description	-	Describe how the asset was impacted and the results of the impact. For example, how did water

Attribute	Field Name	Instructions to Complete (for IAG Members) and Further Description
		enter the facility? For how long did water remain in the facility? What were cascading impacts?
Damage Cost	-	List the amount expended to either repair or replace the asset.
Service Interruption Time	-	Provide how long (in days) that the asset was out of operation due to flooding.
Resiliency Measures Planned or Taken	-	Describe any existing or planned mitigation measures for the asset.
Comments	-	Provide any additional information you believe may be helpful. Please indicate whether recreational space is active or passive, if applicable.

3 PROPERTY

Four analyses related to risk of property to flood impacts comprise the CRB Vulnerability Assessment:

1. An exposure analysis, which considers the number and occupancy type of buildings exposed to impacts from coastal flooding and sea level rise and stormwater flooding
2. An evaluation of Boston's property value exposed flood impacts from coastal flooding and sea level rise
3. A consequence analysis of structure damage and contents loss that can be expected from coastal flooding and sea level rise
4. A consequence analysis of expected displacement costs due to flood impacts. Displacement costs are those expected to be borne by its occupants when a building becomes uninhabitable due to flood damage. The displacement consequence analysis considers one-time costs for moving and/or renting another residence, and monthly allowances for rent or storage space

Each of the aforementioned analyses were completed for the 10 percent, 2 percent, 1 percent, and 0.1 percent annual chance events, or frequencies, for three different sea level rise scenarios: 9 inches, 21 inches, and 36 inches. In total, results of the four aforementioned analyses are reported for at least 12 coastal flooding and sea level rise circumstances. Analyses that evaluate building and property value exposure to coastal and riverine flood impacts also include a fifth frequency: the average monthly highest tide for each sea level rise scenario (see the **Hazard Data Development Appendix** for the development of this scenario). The exposure analysis for stormwater flooding considers the 10 year, 24 hour rain event for the same sea level rise scenarios. This methodology explains the process and approach performed by CRB Analysts to yield the results of each analysis.

3.2 Structure Exposure Analysis

The structure exposure analysis examines the structures at risk to coastal flooding and sea level rise circumstances, as well as stormwater flooding scenarios. Once CRB analysts finalized the general building stock, the exposure analysis was conducted in ArcGIS using the "Select by Location" tool. CRB analysts used the intersection feature of the tool, and selected structures that were either fully or partially within the flood inundation area. Results were exported into GIS, where analysts compiled the data and examined the results for trends in the number and occupancy type of buildings by neighborhood. The Citywide Vulnerability Assessment and the Focus Area assessments describe trends; exposure data for all of Boston is located in the **Detailed Result Appendix**.

3.2.1 Exposure Analysis Limitations

- Results of the exposure analysis are dependent upon the accuracy and integrity of the general building stock, and thus the exposure analysis must continue to be updated and maintained with the general building stock
- The exposure analysis for stormwater flooding scenarios selected buildings that intersected the stormwater flood extents with a -1 foot buffer. The negative buffer was used to eliminate buildings that had miniscule ponding areas located within a building footprint, as analysts considered such instances to be errors in the hazard data.
- Exposure by definition does not consider site-specific conditions such as structure elevations and flood elevations, but simply identifies structures that may be exposed to a number of flood impacts such as structural damage, contents loss, property value degradation, and access issues.
- This analysis imposes future expected conditions on the current building stock. The analysis assumes no change to the existing building stock.

3.3 Property Value Exposure Analysis

The approach to conduct the Property Value Exposure Analysis mirrors that described in the **Structure Exposure Analysis** section above, and adds the assessed value of exposed property (building value and land value) to the evaluation. The Boston Assessing data provides the assessed value for most assessing records; assessed value is the valuation placed on a property for the purposes of taxation (See Footnote 11). Trends related to property value exposure is provided in the CRB Citywide Vulnerability Assessment and Focus Area assessments; raw data on exposed property value by structure use category for all of Boston and each focus area is provided in the **Detailed Result Appendix.**

3.3.1 Property Value Exposure Analysis Limitations

- The Property Value Exposure Analysis only considers property value exposed to coastal flood impacts. Value of property exposed to stormwater impacts are not evaluated.[17]

[17] Properties with known (mapped) flood risk are also known to experience loss in market value over time, due to the potential for increased operating costs, as well as perception of decreased long term viability. Please see the Citywide Vulnerability Assessment for more on this concept. As stormwater flood risk is unlikely to be mapped for flood insurance

- Only property with existing structures exposed to coastal flood and sea level rise impacts are considered in this analysis, because the property value is linked with the **Structure Exposure Analysis**. Empty lots have not been considered.
- City assessing data provides one comprehensive assessing record for a condominium. This record is the Condo Main. CRB analysts assume that Condo Main records report the property value for all records within a condominium, and used the Condo Main record to obtain property value for condominiums. Any parcels with a Condo Main PTYPE (995) were assigned the Condo Main assessed value in GIS; this value was then distributed across buildings on the parcel as described above.
- This analysis imposes future expected conditions on the current building stock. The analysis assumes no change to the existing building stock.

3.4 Infrastructure Exposure Analysis

The Infrastructure Exposure Analysis is similar to the Structure Exposure Analysis in that it examines the location of infrastructure assets and systems in relation to expected extents of coastal and riverine flooding with sea level rise, as well as stormwater flooding scenarios. The Infrastructure Exposure Analysis differs, in that not all infrastructure assets are located within a structure and that much of the data is maintained in point and polyline files. This is particularly the case with the transportation infrastructure system, such as roads, tunnels, bridges, and other underground assets. As such, CRB analysts conducted the Infrastructure Exposure analysis in ArcGIS using the "Select by Location" tool and incorporated a 15-foot buffer to account for assets that are structure-based, so that any exposure of the asset to flood impacts was considered in the analysis. CRB analysts manually screened each infrastructure asset to confirm exposure to the various flood frequencies and sea level rise scenarios analyzed within this report. Due to data sensitivity and integrity concerns, the exposure analysis was limited to the below categories. IAG members had the choice of conducting their own exposure and consequence analysis using the CRB's coastal and riverine flood hazard data. These members provided a qualitative description of expected effects of various coastal and riverine flood hazard conditions to CRB analysts for inclusion in the report.

Results of the exposure analysis are presented within each focus area of the Vulnerability Assessment. Evaluation may be presented qualitatively within the Vulnerability Assessment, or in a custom format,

purposes (and may be addressed through direct infrastructure improvements), the property market value exposure analysis does not add the same informative value for understanding stormwater flood risk.

for some sectors and assets owned by specific entities required non-disclosure agreements in order to share data or analyses.

- Public transit assets (including commuter rail, bus routes, and rapid transit)
- Evacuation routes
- Central artery routes
- Hospitals and health centers
- Schools, colleges, and universities
- Publicly-available utility asset information
- Emergency service information (police, fire, emergency medical services, emergency shelters)
- Public housing

3.4.1 Exposure Analysis Limitations

- Results of the exposure analysis are dependent upon the accuracy and integrity of the asset inventory, and thus the exposure analysis must continue to be updated and maintained with the asset inventory.
- Exposure by definition does not consider site-specific conditions such as critical flood elevations for particular infrastructure assets, but simply identifies infrastructure assets that may be exposed to a number of flood impacts such as structural damage, contents loss, property value degradation, and access issues. Furthermore, exposure does not consider full or partial loss of function of infrastructure assets for this reason.
- The exposure analysis does not include all infrastructure assets due to data limitations, as well as privacy and security concerns raised by members of the IAG.

3.5 Structure Damage and Contents Loss Consequence Analysis

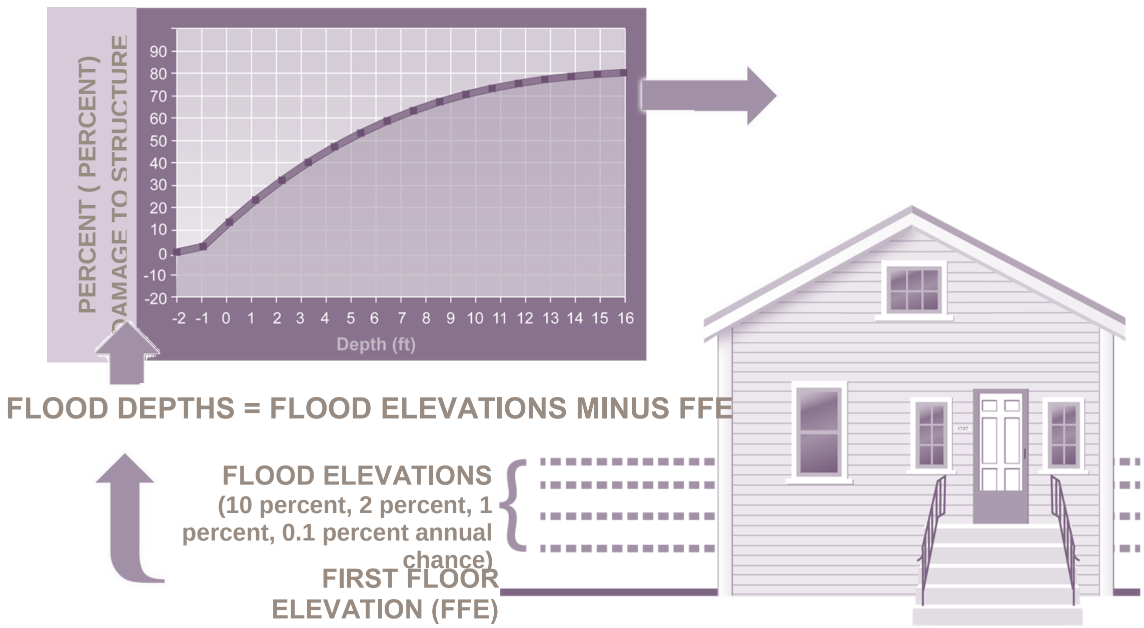
The Structure Damage and Contents Loss Consequence Analysis examines risk to coastal and riverine flooding and sea level rise to buildings and their contents. The consequence analysis does not consider stormwater impacts because the stormwater hazard data is not intended for use to assess individual parcels for flood impacts.

Property losses are evaluated based on depth damage functions (DDFs) developed by the United States Army Corps (USACE) following Hurricane Sandy; flood depths at each structure are cross referenced with DDFs to provide expected percent loss for each structure and its contents. This percent loss is then translated to property loss based on structure replacement costs. The following section provides a detailed discussion of how expected property losses were calculated for the 12 modeled coastal storm and riverine flood circumstances. The CRB Vulnerability Assessment categorizes property loss as structural damage (damage to the building) and contents losses (damage to personal property or inventory). All property damage results have been calculated for Boston using the CRB general building stock as of October, 2016, using 2016 replacement cost values as calculated using RS Means.

3.5.1 Depth Damage Functions

Analysts calculated potential property damages associated with the modeled flood scenarios using standardized DDFs specific to the characteristics and occupancy of a structure. A DDF correlates the depth, duration,[18] and type of flooding to a percentage of expected damage to a structure and its contents, including inventory. The USACE produces DDFs that can be used to model direct physical damages. Following Hurricane Sandy, the USACE developed DDFs specific to the Northeast for coastal flooding in a report titled the North Atlantic Coast Comprehensive Study (NACCS). As this information contains the most current and best available data, analysts used these functions to evaluate direct physical damages. The image below provides an illustration of how DDFs are applied. Figure 2 provides a sample depth damage relationship from the USACE NACCS.

[18] Duration is not a modeled output in the hazard data used for the evaluation. Duration is assumed within the DDFs based on the flood source type.



Example application of depth damage functions adapted from FEMA's Benefit Cost Analysis Training Unit 3[19]

Coastal flooding DDFs are specific to hazard conditions and the primary cause of damage: inundation, wave, or erosion. Saltwater inundation DDFs obtained from the NACCS study were used by analysts to model damages as a result of coastal and riverine flooding with sea level rise.

3.5.2 Data Sources

BCA analysts utilized the following data sources to calculate expected structure, contents and inventory losses avoided:

- **CRB General Building Stock (2016).** Nearly all attributes in the CRB General Building Stock were used to determine physical damages, including square footage, number of stories, building elevation, and building use.
- **RS Means Building Construction Cost Data (2016):** This publication provides location-specific building replacement square foot costs for 160 building occupancy types. Using RS Means,

[19] It should be noted that calculations typically involve the 10 percent, 2 percent, 1 percent and 0.2 percent annual chance events. The CRB has substituted the 0.2 percent annual chance event with the 0.1 percent annual chance event in order to understand impacts at that severity of storm. As such, damage cost calculations may be conservative compared to if the 0.2 percent annual chance had been incorporated.

analysts calculated building replacement square foot costs for the various structure types in Boston.

- **USACE North Atlantic Coast Comprehensive Study (NACCS) Physical Depth Damage Function Summary Report (2015):** Following Hurricane Sandy, the USACE collected empirical data to estimate the damages that would occur from future events. This report produced coastal damage functions for residential, non-residential, and public property. DDFs were obtained from this study to estimate direct physical damages related to modeled storm surge scenarios.
- **USACE West Shore Lake Pontchartrain Hurricane and Storm Damage Risk Reduction Study (2014):** This study conducted by the USACE produced contents-to-structure ratio values (CSRVs) for residential and non-residential structures. CSRVs were used as a percentage of the total building replacement values to determine total contents replacement values for structures in the project area. While produced for a separate region, analysts determined this study to be the best and most recent data available for use with the DDFs.
- **Modeled Inundation Depth Data with Sea Level Rise:** Flood elevations for the 10 percent, 2 percent, 1 percent, and 0.1 percent storm events determined approximate flood depths inside structures. Each of the four frequencies were considered for three different sea level rise scenarios: 9 inches, 21 inches, and 36 inches. In total, 12 situations of damage estimates were evaluated.

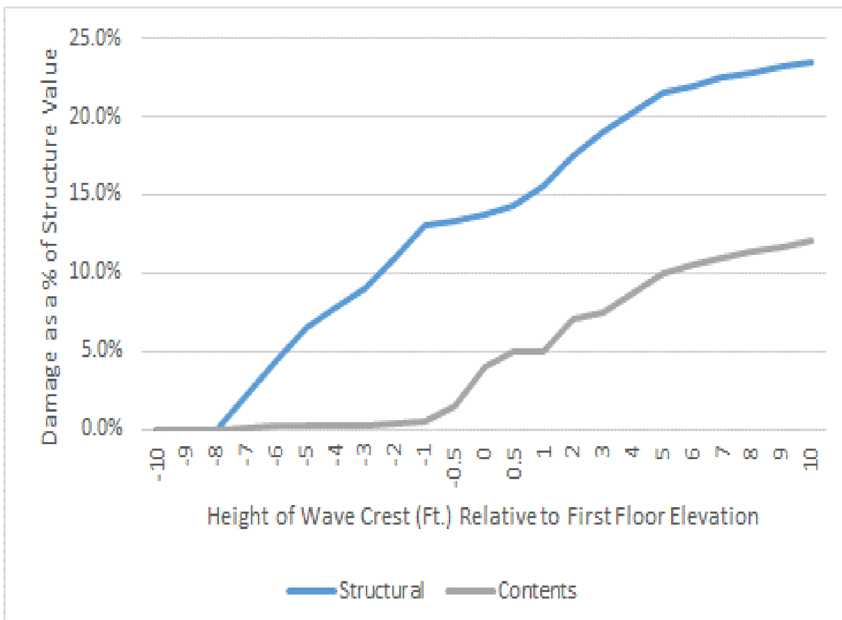


FIGURE 2. EXAMPLE EXPECTED STRUCTURAL AND CONTENTS DAMAGE FROM INUNDATION, NACCS URBAN HIGH RISE PROTOTYPE. DAMAGE AT NEGATIVE FLOOD DEPTHS ACCOUNTS FOR IMPACTS TO MECHANICAL, ELECTRICAL, AND PLUMBING SYSTEMS THAT MAY BE LOCATED AT OR BELOW GRADE.

3.5.3 Analysis Steps

Map Structure Type and Occupancy to Depth

Damage Functions, Replacement Values, and Hazus Occupancy Types

Structures may be classified according to both construction features (type) and use (occupancy). Building types and occupancies can be mapped to classifications used by RS Means to estimate replacement value for the structure. Each mapping to PTYPE required an independent evaluation. Analysts completed the following mappings based on PTYPEs:

- PTYPEs to USACE NACCS prototypes to assign appropriate DDFs
- PTYPEs were mapped to Hazus occupancy classes[20] to estimate a replacement value for structures, as well as apply the appropriate displacement and restoration time multipliers, one-time disruption costs, and for certain uses, the percent owner occupancy

Complete Square Footage Analysis

Damages to NACCS prototypes must be assessed based on the square footage within a certain number of stories NACCS identifies for each prototype's damage function.[21] The number of stories analyzed by the DDF is related to the structure type and the expected location and value of mechanical, electrical, and plumbing (MEP) assets in buildings. A significant portion of a building's value is captured in MEP assets; damage costs to these assets can therfore be disproportionate to those of other contents. Urban high rise damage functions, for example, analyze damages as a percent of the square footage of the first ten floors given the NACCS assumption that MEP assets are located within the basement or first floor of the structure.

To calculate the structure square footage for the consequence analysis, analysts multiplied the square footage per floor by the prototype number of stories identified in the USACE NACCS (refer to Table 9 for an example) or the total number of stories, whichever is less, for each structure. Certain PTYPEs represent structures that are of mixed uses. For structures identified as mixed use, an analysis square footage is developed for both residential and commercial square footage. CRB analysts used the analysis square footage to calculate the building and contents replacement value relavent for the analysis.

TABLE 9. USACE NACCS, NUMBER OF STORIES PER PROTOTYPE/DEPTH DAMAGE FUNCTION ANALYSIS (EXAMPLE)

Prototype No.	Building Types	Stories (for Analysis)

20 Hazus occupancy classes are a building occupancy classification system developed by FEMA Hazus-MH Flood Technical Manual to categorize like buildings so that standard values can be applied to similar structure types.

21 U.S. Army Corps of Engineers. North Atlantic Coast Comprehensive Study (NAACS). http://www.nad.usace.army.mil/CompStudy

1A-1	Apartment 1-Story, No Basement	1
1A-3	Apartment 3-Story, No Basement	3
2	Commercial Engineered	2
3	Commercial Non-Engineered	1
4A	Urban High Rise	10
4B	Beach High Rise	10
5A	Residential 1-Story, No Basement	1
5B	Residential 2-Story, No Basement	2
6A	Residential 1-Story, With Basement	1
6B	Residential 2-Story, With Basement	2
7A	Building on Open Pile Foundation	1
7B	Building on Pile Foundation with Enclosures	1

Source: North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk. Physical Depth Damage Function Summary Report. January 2015.

Calculate the Building and Contents Replacement Value

Building replacement values (BRVs) and Contents Replacement Values (CRVs) are required to determine expected damage to buildings. These values are ultimately applied to the analysis square footage and the percent structural and contents damage related to the flood depth in the DDFs to determine expected damages. Analysts used RS Means 2016 Square Foot Costs to obtain replacement values.

Replacement values are different from the assessed market value referenced above, because it is considered an estimate of the cost to construct an identical structure of the same type and occupancy using today's market values for materials, labor costs, and considering new technologies and regulations that may affect the construction process.

Building Replacement Value (BRV)

The BCA Re-engineering Guide defines the BRV as "the building replacement value for a specific component of the building, expressed in dollars".[22] CRB analysts used the Hazus occupancy classes[23] and obtained building replacement values from RSMeans square footage costs for each occupancy class.

22 Federal Emergency Management Agency. Benefit Cost Analysis Re-engineering Guide. Full Flood Data. 2009. Located at: http://www.fema.gov/media-library-data/20130726-1738-25045-2254/floodfulldata.pdf

23 Hazus occupancy classes represent a certain building type based on use, and the FEMA Hazus-MH Flood Technical Manual applies an average square footage to each occupancy class. This average square footage was used to choose the appropriate replacement value per square foot from the RSMeans cost data book.

RSMeans is a construction cost-estimating resource published each year often used by engineers to evaluate different construction cost possibilities. Labor and material costs are captured and other information such as city cost indexes, productivity rates, crew composition, and contractors overhead and profit rates are available. Analysts used the appropriate RSMeans city cost indices of 1.23 for residential uses and 1.18 for commercial uses in order to accommodate Boston-specific construction conditions. Table 10 below shows the BRV values determined from RSMeans that are applicable to this analysis with the city cost index increase for Boston. The building replacement value represents the cost to repair or rebuild damaged buildings in current dollars.

Mixed Use Building Occupancies

It is common for multiple story buildings to serve multiple uses in Boston. Analysts identified mixed-use structures using PTYPES, and assumed that commercial areas are contained to the first two floors of a structure, if the building is over two stories tall. If the building is two stories tall, analysts assumed that the first floor is commercial space. This assumption was confirmed through the quality control review described in the **Building Information Assumptions and Limitations Section.** RSMeans multiplied the commercial BRVs and the residential BRVs by the area of the commercial and residential space within a building, respectively, and added the values together to obtain a total BRV for the analyzed square footage of the building.

Contents Replacement Value (CRV)

The USACE NACCS does not include content replacement ratios, therefore CRB analysts used the next best available data. The CRV is based on the contents-to-structure ratio values (CSRV) for residential and non-residential structures from data obtained through surveys in the *West Shore Lake Pontchartrain Hurricane and Storm Damage Risk Reduction Study.*[24] The total building and contents exposure for the analysis square footage provide a general understanding of the total value of building square footage (and its contents) at risk to flooding in the project area from the 1 percent annual chance flood event. The CSRVs used in the analysis are shown in Table 10. To calculate the total contents replacement value, analysts multiplied the total BRV by the appropriate CSRV, which is mapped to the Hazus occupancy class. Because the contents values are based on percentages, they increase coincident with an increase in the BRV and therefore do not need to be updated to Boston values for this analysis.

Mixed Use Building Occupancies

24 USACE. 2014. West Shore Lake Pontchartrain Hurricane and Storm Damage Risk Reduction Study – Final Integrated Feasibility Study Report and Environmental Impact Statement. November.

- The CSRV for a specific type of residential or commercial use was assigned to the appropriately categorized analysis square footage
- Next, the CSVR was applied to the BRV to obtain the CRV for each use type
- The CRV for all use types analyzed in the analysis square footage were added together to obtain the total CRV

TABLE 10. REPLACEMENT VALUES

Hazus	Occupancy Code	BRV	CSRV	CRV
RES1	Single Family Dwelling	$143.14	0.69	$98.77
RES2	Mobile Home	$137.47	1.14	$156.71
RES3A	Multi Family Dwelling - Duplex	$117.76	0.69	$81.25
RES3B	Multi Family Dwelling – 3-4 Units	$227.31	0.69	$156.85
RES3C	Multi Family Dwelling – 5-9 Units	$227.31	0.69	$156.85
RES3D	Multi Family Dwelling – 10-19 Units	$216.42	0.69	$149.33
RES3E	Multi Family Dwelling – 20-49 Units	$209.84	0.69	$144.79
RES3F	Multi Family Dwelling – 50+ Units	$202.67	0.69	$139.84
RES4	Temporary Lodging	$211.01	0.69	$145.59
RES5	Institutional Dormitory	$242.70	0.69	$167.46
RES6	Nursing Home	$246.88	0.69	$170.35
COM1	Retail Trade	$137.67	1.19	$163.82
COM2	Wholesale Trade	$133.41	2.07	$276.16
COM3	Personal and Repair Services	$160.45	2.36	$378.66
COM4	Business/Professional/Technical Services	$198.63	0.54	$107.26
COM5	Depository Institutions	$299.43	0.54	$161.69
COM6	Hospital	$426.82	0.54	$230.48
COM7	Medical Office/Clinic	$241.96	0.54	$130.66
COM8	Entertainment & Recreation	$252.25	1.7	$428.83
COM9	Theaters	$211.95	0.54	$114.45
COM10	Parking	$89.34	0.54	$48.24
IND1	Heavy	$151.75	2.07	$314.12
IND2	Light	$133.41	2.07	$276.16
IND3	Food/Drugs/Chemicals	$205.59	2.07	$425.56
IND4	Metals/Minerals Processing	$205.59	2.07	$425.56
IND5	High Technology	$205.59	2.07	$425.56
IND6	Construction	$133.41	2.07	$276.16

Hazus	Occupancy Code	BRV	CSRV	CRV
AGR1	Agriculture	$133.41		$0.00
REL1	Church/Membership Organizations	$213.29	0.55	$117.31
GOV1	General Services	$169.99	0.55	$93.49
GOV2	Emergency Response	$283.68	1.5	$425.52
EDU1	Schools/Libraries	$228.41	1	$228.41
EDU2	Colleges/Universities	$200.58	1	$200.58

Determine Flood Depths Based on Modeled Flood Scenarios

Analysts subtracted grade elevations for each structure footprint in the study area from the modeled 10 percent, 2 percent, 1 percent, and 0.1 percent flood elevations for each sea level rise scenario in order to determine the expected flood depths in structures. The DDFs provided in the USACE NACCS account for expected first floor elevation (FFE) by occupancy type and age, as well as the presence of MEP assets located in the basement. Since these building attributes have been incorporated into the DDFs, it is not necessary to account for FFE in the structure inventory. Nevertheless, many of the structures in the study area have FFEs at grade or are split level homes that have living space or basements vulnerable to flooding at or below grade elevation (confirmed through Google Earth). To determine the depth of flooding for structures in the study area, analysts obtained the maximum modeled flood elevation within a building footprint for each flood scenario. The average grade elevation within the building footprint was then subtracted from the respective flood elevations to obtain a flood depth in each structure for each scenario.

Calculate Percent Damage and Physical Loss Values

As previously mentioned, DDFs are a relationship between the depth of floodwater in a structure and the percent of damage that can be attributed to the flooding. Once the expected flood depths were defined for each storm surge scenario, analysts applied the DDFs to estimate the percent of structural and contents damage costs. The percent of structural and contents damage is related to 1-foot depth increments, and are multiplied by a structure or contents total replacement value to produce a physical loss value in dollars.

3.5.4 Quality Control Evaluations

In order to reduce uncertainties and increase the accuracy of the evaluation, analysts performed several quality control actions as described in the following subsections.

3.5.4.1 QA/QC of PTYPES

As discussed in the **Data Integrity and Fidelity** section of this report, PTYPES were confirmed through Google Streetview, especially of those buildings that had the highest damage calculations in a focus area. Adjustments were made where appropriate. Any structures for which accurate building occupancies were unclear were subject to a site-specific evaluation using GIS and Google Earth street view, as well as by consulting with team members with specific local knowledge.

3.5.4.2 QA/QC of Direct Physical Damages

Structures that experienced a high percent loss and/or those with high replacement costs required site specific analysis. Analysts reviewed PTYPES, expected flood depths, ground elevation, DDF, and replacement value to ensure the accuracy of the data and the expected damages. Many inaccuracies were due to incorrect assignment of PTYPES to a building. This data point informs the DDF that is used to determine the percent damage. Furthermore, accessory structures and utility buildings were removed from the analysis due to the absence of appropriate DDFs in the NACCS model inventory for these uses and the associated risk of under or overestimating losses.

3.5.5 Assumptions

- The USACE NACCS DDFs account for underground networks by applying a percent damage for negative flood depths. The underground networks of the City could not be analyzed due to security concerns, lack of available data, and budget / time constraints.
- The NACCS DDFs did not provide percent loss for all flood depth intervals for all occupancies, and provided no percent loss above ten feet of flood depth. As such, analysts developed trend interpolations based on the preceding three available flood depths for missing DDFs. A similar approach was used for flood depth gaps below zero flood depth, using averages between flood depths, where available.
- The DDFs do not assume complete loss beyond 50 percent damage, as is often assumed for use with benefit cost analyses, as well as substantial damage determinations. Further, the impacts of codes and standards in restoration are not considered in the analysis. As such, direct physical damage costs may be conservatively low.
- For PTYPES that contain a mixture of residential and commercial uses, commercial occupancies are assumed to be located on the bottom two floors with residential above (for structures with over two stories).

3.6 Displacement Consequence Analysis

Displacement costs are those borne by occupants during the time when a building becomes uninhabitable due to expected flood damage, and are applicable to both residential and non-residential property owners. To determine displacement values, CRB analysts consider two interrelated methodologies, which estimate the time and cost of displacement for various building types: relocation costs and business interruption costs.

Relocation costs and business interruption are two consequences that result from disaster impacts. Relocation costs are associated with moving a household or a business to a new location and resuming life or business in that new location. Business interruption is associated income lost as a result of an event that interrupts the operations of the business, or the removal of a piece of real estate, both rental and sale properties, from the market as a result of disaster impacts.

Relocation costs are derived from displacement time, while business interruption is based on restoration time (refer to Figure 3). Some businesses may relocate and resume business elsewhere; some businesses may be unable to relocate while they are displaced. Therefore, impacted businesses or residents may incur both, one, or neither of relocation costs and business interruption. For example, a business may have to restock its damaged inventory before being able to relocate and start operations in a new space, thus incurring both business interruption and relocation costs.

Displacement Time

- Derived from DDFs that relate a depth of flooding to an amount of time that a structure is not usable.
- Relocation costs are based on displacement time.

Restoration Time

- Time for physical restoration of the damage of the building, as well as time for clean up, inspections, permits, and delays due to contractor availability.
- Based on occupancy type, flood depth, and extent of damage.
- Business interruption costs are based on restoration time.

FIGURE 3. DISPLACEMENT AND RESTORATION TIME COMPARISON

CRB Analysts took care to appropriately account for each cost associated with displacement without duplication by applying a FEMA Hazus Business Interruption Time Multiplier, categorized by business type, to restoration time. The overall approach taken to identify appropriate relocation costs and business interruption is as follows:

1. Identify flood depths and damage expected to occur in 1 percent, 2 percent, 1 percent, and 0.1 percent annual chance flood events within Boston for three sea level rise scenarios
2. Calculate expected displacement and building restoration times based on flood depths and building use
3. Apply Business Interruption Time Multipliers to restoration time based on Hazus occupancy class and extent of damage
4. Use displacement and adjusted building restoration times to calculate relocation costs and business interruption without benefit duplication

3.6.1 Data Sources

- **Hazus-MH 2.1 Flood Technical Manual and Earthquake Technical Manual:** Methodologies from Hazus-MH 2.1 were used to determine restoration time, as well as the costs of relocation, supplemented with local rental rates. Specifically, the Flood Technical Manual provided restoration time and the Earthquake Technical Manual provided the Business Interruption Time Multipliers based on damage category.[25]
- **Hazus 2.1 One-time Disruption Cost Defaults**: Hazus provides national one-time relocation costs per square foot based on Hazus occupancy class. These costs are provided in 2006 dollars and have been normalized to 2016 dollars based on inflation.
- **US Census Bureau American Community Survey (2014)**: The percent owner occupancy by census tract for residential uses was obtained from local 2014 American Community Survey five year estimates.

25 The Earthquake Technical Manual is applicable because of the hazard neutral approach to loss of function; additionally, Hazus methodologies related to flood hazard are often adapted from methods developed for the earthquake hazard. While the cause and extent of damage differ for these two hazard types, the consequences of such hazards (damage, displacement, loss of function) are generally the same. As such, the Flood Technical Manual will often refer to the Earthquake counterpart for greater detail, as was the case in obtaining information for detailed calculations necessary to determine business interruption.

- **Hazus 2.1 Percent Owner Occupancy Defaults**: Hazus provides percent owner occupancy for non-residential uses by Hazus occupancy class (local value was not available).
- **Hazus 2.1 Business Interruption Time Modifiers**: Modifiers represent median values for probability of business or service interruption for Hazus occupancy classes, based on damage state and restoration time.
- **Direct Physical Damages**: Flood impacts were modeled for different flood scenarios to determine which structures are expected to flood and the depth of flooding within the structure (see **Structure Damage and Contents Loss Consequence Analysis** above).
- **FEMA BCA Toolkit 5.1**: Depth displacement tables were not provided with the USACE NACCS DDFs used in the Direct Physical Damage evaluation. As such, analysts extracted displacement tables from the Toolkit to estimate displacement time for structures based on flood depth.
- **Local Rental Rates.** Analysts researched local rent rates for Boston neighborhoods and applied these rates by occupancy. Local residential rental rates were established from an online survey of different sizes and types of residential spaces currently available for rent within Boston. Local commercial rental rates were obtained in the same manner as residential rental rates; neighborhood-specific rental rates were developed for both residential and non-residential rentals. Loopnet was used to obtain current asking commercial rental rates, and Trulia, and Zillow (all online real estate services) were used to conduct the survey.

3.6.2 Analysis Steps

The following steps were taken in order to determine expected displacement impacts for different modeled flood circumstances.

1. Identify Impacted Structures: The **Structure Damage and Contents Loss Consequence Analysis** identified structures expected to be impacted at the 10 percent, 2 percent, 1 percent, and 0.1 percent annual chance events for three sea level rise scenarios.
2. Identify Impacted Square Footage: The total impacted square footage per occupancy class was identified by using the total square footage of the first floor for structures that are expected to experience less than ten feet of flooding. The total square footage of the first two floors is used for structures experiencing more than ten feet of flooding.

3. Identify and Apply Percent Owner Occupied by Occupancy: For residential uses, census tract data provided the percent owner occupied. All non-residential uses were assigned default percent owner occupancy obtained from Hazus-MH 2.1.
4. Identify Rental Rates by Occupancy: Analysts calculated an average annual rent price per square foot for residential and non-residential uses in Boston, identifying specific rental rates per neighborhood. These values were converted to an average price per square foot per day (Price/SF/Day), for use in the Relocation Costs calculation outlined in Step 6.
5. Evaluate Displacement Time: The estimated flood depth within each structure is correlated to USACE depth displacement tables to estimate displacement time for each modeled flood scenario.
6. Process Relocation Costs: The Hazus Flood Technical Manual provides guidance to calculate relocation costs to building occupants based on occupancy type:[26]

$$\mathbf{REL_i = \Sigma \text{ if } percentDAM - BL_{i,j} > 10 \text{ percent}: Fa_{i,j} * [\,(1 - percentOO_i) * (DC_1) + percentOO_i * (DC_i + RENT_i * DT_{i,j})]}$$

Where:

REL_i	Relocation costs for occupancy class l (in dollars)
$Fa_{i,j}$	Floor area of occupancy group i and depth j (in square feet)
$PercentDAM - BL_{i,j}$	Percent building damage for occupancy i and water depth j, (from depth-damage function), if greater than 10 percent
DC_i	Disruption costs for occupancy i (in dollars)
$DT_{i,j}$	Displacement time (in days) for occupancy i and water depth j (in days)
$percentOO_i$	Percent owner occupied for occupancy l
$RENT_i$	Rental cost for occupancy l (in $\$/ft^2/day$)

26 It is important to note that this equation incorporates only owner-occupied structures when calculating displacement values. The reason for this is that a renter who has been displaced would likely cease to pay rent to the building owner of the damaged property, and instead would pay rent to a new landlord. As such, the renter could reasonably be expected to incur no new rental expenses. Conversely, if the damaged property is owner-occupied, then the owner will have to pay for new rental costs in addition to any existing costs while the building is being repaired. This model assumes that it is unlikely that an occupant will relocate if a building is slightly damaged (less than 10 percent structure damage).

7. Evaluate Restoration Time: The estimated flood depth within each structure cross-referenced to the restoration time by occupancy provided by the Hazus 2.1 Flood Hazard Technical Manual[27] to determine the restoration time for each modeled flood scenario.
8. Assign Damage State: CRB analysts assigned FEMA damage states to each impacted structure based on the percent damage to each structure for each modeled flood scenario (see Table 11). Percent damage is evaluated based on the flood depth within a structure.

TABLE 11. DAMAGE STATE CORRELATIONS

Damage State	None	Slight	Moderate	Extensive	Complete
Correlating Percent Damage Threshold	0%	1%	5%	25%	50%+

9. Determine Business Interruption Time (Adjusted Restoration Time): Business interruption time determined by applying the Business Interruption Time Multiplier to expected restoration periods. Business Interruption Time Multipliers vary based on occupancy and damage state. CRB analysts calculate business interruption costs in accordance with the methodology described in the **Economy** section. Multipliers are provided in Table 12 below.

TABLE 12. HAZUS TIME MULTIPLIERS BY OCCUPANCY CODE

HAZUS Occupancy Code	OC Description	Damage State				
		None	Slight	Moderate	Extensive	Complete
RES1	Single Family Dwelling	0	0	0.5	1	1
RES2	Manufactured Housing	0	0	0.5	1	1
RES3	Multifamily	0	0	0.5	1	1
RES4	Hotel/Temporary lodging	0	0	0.5	1	1
RES5	Institutional Dorm	0	0	0.5	1	1
RES6	Nursing Home	0	0	0.5	1	1
COM1	Retail Trade	0.5	0.1	0.1	0.3	0.4
COM2	Wholesale Trade	0.5	0.1	0.2	0.3	0.4
COM3	Personal and Repair Services	0.5	0.1	0.2	0.3	0.4
COM4	Profession/Tech/Business Services - Office	0.5	0.1	0.1	0.2	0.3

[27] The Hazus Technical Manual provides value ranges for restoration time. Analysts used the upper and lower bounds of these ranges for thresholds correlated to flood depths and interpolated the values in between any missing intervals.

COM5	Banks	0.5	0.1	0.05	0.03	0.03
COM6	Hospital	0.5	0.1	0.5	0.5	0.5
COM7	Medical Office/Clinic	0.5	0.1	0.5	0.5	0.5
COM8	Entertainment and Recreation	0.5	0.1	1	1	1
COM9	Theaters	0.5	0.1	1	1	1
COM10	Parking	0.1	0.1	1	1	1
IND1	Heavy	0.5	0.5	1	1	1
IND2	Light	0.5	0.1	0.2	0.3	0.4
IND3	Food/Drugs/Chemical Lab	0.5	0.2	0.2	0.3	0.4
IND4	Metals/Minerals Processing	0.5	0.2	0.2	0.3	0.4
IND5	High Technology/Lab	0.5	0.2	0.2	0.3	0.4
IND6	Construction	0.5	0.1	0.2	0.3	0.4
AGR1	Agriculture	0	0	0.05	0.1	0.2
REL1	Church	1	0.2	0.05	0.03	0.03
GOV1	General Services (Town Hall)	0.5	0.1	0.02	0.03	0.03
GOV2	Emergency Response (Police Station)	0.5	0.1	0.02	0.03	0.03
EDU1	Schools/Libraries	0.5	0.1	0.02	0.05	0.05
EDU2	Colleges/Universities	0.5	0.1	0.02	0.05	0.05

10. Complete the Analysis: The analysis described above was completed for damages expected at four recurrence intervals (10 percent, 2 percent, 1 percent, and 0.1 percent annual chance flood events) for three sea level rise scenarios (9 inches, 21 inches, 36 inches) to estimate Relocation costs and Business Interruption Time.

3.6.3 Assumptions

The following assumptions were made to prevent double-counting benefits associated with relocation costs and business interruption costs:

- Both relocation costs and business interruption are only calculated for floors expected to be directly impacted by floodwaters. In reality, there are times when the entire structure will be displaced as a result of flood impacts. As a result, this approach produces conservative results.
- **Relocation-specific Assumptions:**

  - Depth displacement tables used in the analysis do not consider flooding below grade. Utilities and other critical assets often lie below grade within Boston. When these areas flood, occupants may be displaced, even if flood waters do not reach above the first floor. Such displacement is not captured in the analysis.
  - The depth displacement tables do not extend beyond 16 feet of flood depth. As such, displacement periods for flood depths above 16 feet are assumed to match the time period for displacement at 16 feet.
- **Business Interruption-specific Assumptions:**
  - FEMA assumes that business interruption does not occur until the building reaches greater than 10 percent structural damage.
  - Some businesses will choose to relocate their operations while structure damage is being repaired to minimize output loss. To do so, these businesses may rent additional space elsewhere, thus choosing to incur relocation costs during building restoration as opposed to economic losses; this scenario assumes that business output will remain the same upon relocation.
  - The analysis assumes that all interrupted businesses are eventually able to return to business as usual. This a conservative assumption; FEMA's Institute for Business and Home Safety states that "one-fourth of all businesses that close because of a disaster never reopen." This number is statistically considerably higher for small businesses (roughly 40 percent).
  - Analysts assume, in concurrence with Hazus 2.1, that businesses that qualify as entertainment (COM8), theatres (COM9), parking facilities (COM10), and heavy industry (IND1) will not relocate after a disaster due to the type of activities that take place in such structures. As such, no relocation costs are associated with these uses, though business interruption costs are calculated.
  - The Hazus Technical Manual provides value ranges for restoration time. Analysts used the upper and lower bounds of these ranges for thresholds correlated to flood depths and interpolated the values in between any missing intervals.

4 PEOPLE

The CRB Vulnerability Assessment analyzed how climate-related hazards, coastal and riverine flooding with sea level rise in particular, may affect Boston residents. These analyses include the following:

1. An exposure analysis, which considers the number of people that live in residential structures exposed to impacts from coastal, riverine, and stormwater flooding with sea level rise.
2. A consequence analysis, which reflects the number of impacted residents that may need to shelter if they cannot access their homes due to coastal and riverine flooding, specifically. Shelter needs are based on flood depths and population characteristics such as age and income.
3. A consequence analysis of expected psychological distress as a result of property damage or displacement, also known as Mental Stress and Anxiety impacts, as a result of coastal and riverine flooding. The cost of treatment for post-disaster mental health impacts is the basis of this consequence analysis.
4. A consequence analysis of expected work productivity impacts as a result of mental illness, which reflects an estimate of lost work days for people whose residences are impacted by coastal and riverine flooding.

Each of the aforementioned analyses exists for the 10 percent, 2 percent, 1 percent, and 0.1 percent annual chance events, or frequencies, for three different sea level rise scenarios: 9 inches, 21 inches, and 36 inches. In total, results of the above analyses are reported for 12 coastal flooding and sea level rise circumstances. Analyses that evaluate population exposure to coastal and riverine flood impacts also include a fifth frequency: the average monthly highest tide for each sea level rise scenario. This methodology explains the process and approach performed by CRB Analysts to yield the results of each analysis.

4.1 Exposed Persons Analysis

The Exposed Persons Analysis uses the **Structure Exposure Analysis** results to estimate the number of people that reside within residential or mixed use structures located within the inundation area for coastal and riverine floods. The first step to conduct the Exposed Persons Analysis begins by estimating the number of residents per building throughout Boston, using the CRB general building stock and U.S. 2010 Census data provided by census tract. Building populations were estimated per the steps below.

CRB Analysts compiled the results of the analysis and examined them for trends in the number, location, and concentrations of people living in buildings exposed to coastal and riverine flood impacts. Trends are discussed in the Citywide Vulnerability Assessment and the Focus Area assessments; the raw exposure data is located in the **Detailed Results Appendix**.

1. Assign census tracts to structures. CRB analysts used the "Join" tool in ArcGIS to complete this step.
2. Identify the total amount of residential space existing within a census tract. Rather than using the Square Footage Analysis determined in the **Structure Damage and Contents Loss Consequence Analysis**, the entire residential square footage for each building is required for an accurate estimate of population.
3. Divide a structure's residential space by the total amount of residential space within the structure's census tract. This provides a percentage of residential area located within one building.
4. Multiply the percentage of residential area by the total population within the building's census tract. This provides an estimate of the number of people that reside within a building.

4.1.1 Exposure Analysis Limitations

- Results of the Exposed Persons Analysis are dependent upon the accuracy and integrity of the **Structure Exposure Analysis**, and the general building stock.
- The Exposed Persons Analysis likely generates a conservative estimate of the population exposed to coastal and riverine flooding with sea level rise. This analysis does not consider those who work in exposed buildings, or could be affected by disrupted traffic patterns due to flooding.
- U.S. 2010 Census Data was used as the population estimate source in an effort to align with Dr. Atyia Martin's social vulnerability data, which was used to discuss exposed populations with social vulnerability characteristics in the CRB Vulnerability Assessment.
- The Exposed Persons Analysis presents a static representation of the location of residential structures at the time of this report. Future development trends will affect the location and concentration of residential space, which is not reflected within this exposure analysis. Also not reflected in this analysis is expected population growth for Boston, which contributes to the conservative nature of these exposure estimates.

4.2 Shelter Needs Consequence Analysis

Impacted residents may need to shelter if they cannot access their homes due to flooding. Even though the home may not be damaged, people will be displaced if they are evacuated or cannot physically access their property by foot, vehicle, or transit due to flooded roadways and transit systems. This analysis uses flood depths within residential or mixed use structures, and population age and income characteristics to estimate the number of individuals that may require shelter. Low-income individuals, as well as young families and the elderly, are more likely to seek shelter according to FEMA.[28] The population seeking shelter is not assigned a monetary value to avoid double counting benefits associated with Relocation Costs.

4.2.1 Data Sources

- **US Census Bureau American Community Survey (ACS) (2014):** Household income estimates, population counts by age, and persons per household were obtained from the 2014 ACS 5-year estimates. Income and age data are used to weight the displaced population to determine the number of individuals who will seek shelter. Dr. Atyia Martins' Social Vulnerability data was not used in this analysis to ensure that specific data requirements of the methodology are met[29]. Use of such data would imply a level of specificity that cannot currently be known using existing data.
- **Flood depths:** Flood depths for each structure from the **Structure Damage and Contents Loss Exposure Analysis** are used to identify impacted buildings.
- **Structure Population:** The **Exposed Persons Analysis** provides the number of people expected to reside in impacted buildings.

4.2.2 Shelter Needs Analysis Steps

1. Identify Impacted Buildings

Access to an area is assumed to be obstructed at a depth between 6 inches (the typical height of a curb) and 12 inches.[30] For this analysis, any residential unit with a flood depth that equals or exceeds 12

28 HAZUS Flood Technical Manual. FEMA. Pg. 432 Located at: http://www.fema.gov/media-library-data/20130726-1820-25045-8292/hzmh2_1_fl_tm.pdf

29 Specific requirements necessary for the shelter needs analysis include definitions of age factors and income; data related to this information in Dr. Martin's analysis was too broad to confirm.

30 Federal Emergency Management Agency. HAZUS Flood Technical Manual.[web page] Located at: http://www.fema.gov/media-library-data/20130726-1820-25045-8292/hzmh2_1_fl_tm.pdf

inches is expected to cause displacement of residents and create a need for short-term sheltering, at minimum.

2. Displaced Population Likely to Seek Public Shelter

The population within buildings expected to cause resident displacement must be modified to account for the likelihood that an individual may seek out other shelter options such as a hotel or staying with friends or family. Based on the methodology presented in the Hazus-MH Flood Technical Manual, two factors that may impact these choices are income and age (vehicle ownership and other potential factors, such as race or ethnicity, are not considered).[31] Individuals who seek shelter are most likely low-income and/or do not have family in the area; age plays a secondary role, as some individuals may seek shelter even if they have the financial means to do otherwise, such as the young and elderly.[32]

FEMA has developed a constant to adjust for income and age using weight and modification factors (see equation below). Weight and modification factors are based primarily on income, because even though young and elderly families may statistically prefer to use publicly provided shelters, these populations tend to be lower income or on fixed incomes.[33] Default weight and modification factors obtained from the Hazus-MH Flood Technical Manual were used in this analysis, and are provided in Table 13 and Table 14.

$$Constant = (weight\ for\ income * relative\ modificaiton\ factor\ for\ income) + (weight\ for\ age * relative\ modification\ for\ age)$$

For example, the constant for Income Class IM1 and Age Class AM1 is:

$$0.33 = (0.8 * 0.4) + (0.2 * 0.05)$$

Table 15 provides a summary of possible constants.

TABLE 13. WEIGHT FACTORS FOR INCOME AND AGE

Class	Description	Default
IW	Income Weighting Factor	0.8
AW	Age Weighting Factor	0.2

31 Federal Emergency Management Agency. HAZUS Flood Technical Manual. [web page] Located at: http://www.fema.gov/media-library-data/20130726-1820-25045-8292/hzmh2_1_fl_tm.pdf

32 Ibid.

33 Ibid.

TABLE 14. RELATIVE MODIFICATION FACTORS

Class	Description	Default	Default for Communities with 60 percent or More of Households with Income > $35,000
Income			
IM1	Household Income < $10,000	0.4	0.46
IM2	IM2 $10,000 < Household Income < $15,000	0.30	0.36
IM3	$15,000 <Household Income < $25,000	0.15	0.12
IM4	$25,000 < Household Income < $35,000	0.10	0.05
IM5	$35,000 < Household Income	0.05	0.01
Age			
AM1	Population under 16	0.05	-
AM2	Population between 16 and 65	0.20	-
AM3	Population over 65	0.50	-

TABLE 15. CONSTANT FOR EACH COMBINATION OF INCOME AND AGE CLASS

Constant = (IW*IM)+(AW*AM)		
Class	**Default**	**Default for 60 percent HH > 35K**
IM1-AM1	0.33	0.378
IM1-AM2	0.36	0.408
IM1-AM3	0.42	0.468
IM2-AM1	0.25	0.298
IM2-AM2	0.28	0.328
IM2-AM3	0.34	0.388
IM3-AM1	0.13	0.106
IM3-AM2	0.16	0.136
IM3-AM3	0.22	0.196
IM4-AM1	0.09	0.05
IM4-AM2	0.12	0.08
IM4-AM3	0.18	0.14
IM5-AM1	0.05	0.018
IM5-AM2	0.08	0.048

Constant = (IW*IM)+(AW*AM)		
Class	Default	Default for 60 percent HH > 35K
IM5-AM3	0.14	0.108

3. Determine Distribution of Population by Income and Age Class

Data obtained from the American Community Survey provided the percentage of the population in each income and age class.

4. Determine Sheltering Needs

Sheltering needs can be determined using the following equation provided in the Hazus-MH Flood Technical Manual:

$$People\ using\ shelters = \sum_{k=1}^{5}\sum_{m=1}^{3}(constant_{km} * displaced\ population * percentage\ of\ population\ in\ k\ income\ class * percentage\ of\ population\ m\ age\ class)$$

The constants listed in Table 15 for each combination of income and age classes are used with the total displaced population, percentage of the population in the associated income class, and percentage of the population in the associated age class to obtain a total population that will seek shelter for each income and age class combination. This is completed for each combination of income and age class, and the results are added together to obtain the total population that will seek shelter for a flood scenario.

4.2.3 Assumptions

- Sensitivity analyses conducted by FEMA indicated that small modifications in weight and modification factors had little effect on the estimated shelter needs. It was recommended that analysts use default factors unless there are local statistical data available on populations that use shelters. Thus, it is assumed that FEMA national default income and wage factors are applicable to the project area.
- The entire residential population of a structure is displaced when a structure is flooded.
- Shelter needs do not consider displacement associated with pre-event evacuation, only expected direct flood impact.
- When considering displacement costs, the shelter needs approach is considered to be a double-counting when compared to the relocation approach. The relocation approach assumes that all

displaced individuals will require alternative living quarters, thus capturing the costs of individuals that may opt to go to a shelter. Moreover, the number of individuals that will require shelter after a flood event is likely conservative, since other social vulnerability factors are not considered in the analysis. To account for this benefit duplication, costs associated with sheltering displaced populations are not calculated nor incorporated into the analysis.

4.3 Mental Stress and Anxiety Consequence Analysis

Natural disasters threaten or cause loss of health, social, and economic resources, which leads to psychological distress.[34] Research indicates that individuals who experience significant stressors, such as property damage or displacement, are more likely to experience symptoms of mental illness, Post-Traumatic Stress Disorder (PTSD), and higher levels of stress and anxiety after a disaster.[35] As mental health issues increase after a disaster, it is expected that mental health treatment costs will also increase. The American Red Cross (ARC) estimates that 30 to 40 percent of an impacted population will need mental health assistance after a disaster.[36] Post-Hurricane Sandy research demonstrates that there was a measurable spike in mental stress disorders after the event, including PTSD, anxiety, and depression.[37] As such, FEMA has developed standard values to estimate the treatment costs of mental stress in a post-disaster situation, if a person has personally experienced damage to their residence.

4.3.1 Data Sources

- **Federal Emergency Management Agency's (FEMA) Final Sustainability Benefits Methodology Report (2012):**[38] This report provides a method to calculate costs of avoided mental stress and anxiety treatment.
- **Flood depths:** Flood depths for each structure from the **Structure Damage and Contents Loss Exposure Analysis** are used to identify impacted buildings.

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34 Hobfoll, S.E. 1989. Conservation of resources: A new attempt at conceptualizing stress. American Psychologist. 44:513–524. [PubMed: 2648906].

35 Rhodes, J., Chan, C.,Pacson, C., Rouse, C.E., Waters, M., and E. Fussell. 2010.. The Impact of Hurricane Katrina on the mental and physical health of low-income parents in New Orleans. Am J Orthopsychiatry. April; 80(2): 237-247.

36 Welker, Catherine. 2011. American Red Cross Liaison Officer to FEMA Headquarters Disaster Services. Personal correspondence, December 6.

37 Beth Israel Medical Center data indicate a 69 percent spike in psychiatric visits in November 2012. Healthcare Quality Strategies Inc. reviewed Medicare claims before and after Hurricane Sandy in select communities in New Jersey and found that PTSD was up 12.2 percent, anxiety disorders were up 7.8 percent, and depression or proxy disorders were up 2.8 percent.

38 Federal Emergency Management Agency. Final Sustainability Benefits Methodology Report. August 23, 2012.

- **Structure Population:** The **Exposed Persons Analysis** provides the number of people expected to reside in impacted buildings.

4.3.2 Analysis Steps

Mental health treatment costs can be based on three factors: cost, prevalence, and course. Prevalence is the percentage of people who experience mental health problems after a disaster event, and course is the rate at which mental health symptoms reduce or increase over time. Cost is simply the cost of treatment to those who seek it.

1. Determine Prevalence Rate and Course

FEMA's Final Sustainability Benefits Methodology Report[39] uses prevalence percentages and mental health expenses from Schoenbaum (2009) to derive a standard value for mental stress and anxiety costs. Prevalence percentages are adjusted over different time periods. Mild to moderate impacts will reduce over time as treatment is provided, and severe mental health problems may persist much longer, possibly never being fully resolved.[40] For this reason, mild to moderate mental health prevalence percentages reduce over time, while severe mental health prevalence percentages remain consistent after a disaster. Findings from Kessler et al. (2008) support this trend, reporting increasing rates of PTSD and severe mental health issues between six months after a hurricane and approximately one year after.[41] It is possible, if left untreated, that PTSD and severe mental illness can become more entrenched over time, while mild or moderate mental illness symptoms attenuate.[42] Table 16 provides a summary of prevalence considering course over four different lengths of time.[43] It is important to note that this methodology only captures mental health impacts for the first 30 months because evidence of prevalence rates after this time period is not currently available.

39 FEMA. 2012. Final Sustainability Benefits Methodology Report. August 23.

40 Schoenbaum, Michael; Butler, Brittany; Kataoka, Sheryl; Norquist, Grayson; Springgate, Benjamin; Sullivan, Greer; Duan, Naihua; Kessler, Ronald; and Kenneth Wells. 2009. Promoting Mental Health Recovery After Hurricanes Katrina and Rita: What Can Be Done at What Cost. Archives of General Psychiatry, Vol. 66, #8, August.

41 Kessler RC, Galea S, Gruber MJ, Sampson NA, Ursano RJ, and S. Wessely. 2008. Trends in mental illness and suicidality after Hurricane Katrina. Molecular Psychiatry. 13:374–384.

42 Rhodes, J., Chan, C.,Pacson, C., Rouse, C.E., Waters, M., and E. Fussell. 2010.. The Impact of Hurricane Katrina on the mental and physical health of low-income parents in New Orleans. Am J Orthopsychiatry. April; 80(2): 237-247.

43 FEMA. 2014. Updated Social Benefits Methodology Report. December 18.

TABLE 16. PREVALENCE OF MENTAL HEALTH ISSUES AFTER A DISASTER

Time after Disaster	Severe	Mild/Moderate
7-12 months	6 percent	26 percent
13-18 months	7 percent	19 percent
19-24 months	7 percent	14 percent
25-30 months	6 percent	9 percent

Source: FEMA Updated Social Sustainability Methodology Report

2. Determine Cost

Schoenbaum provides an estimate of treatment costs in an ideal scenario where all needs are met. FEMA argues that treatment costs from the study must be adjusted to consider only those with mental health problems who will actually seek out treatment (41 percent).[44] According to Wang et al, of the 41 percent, 16 percent receive adequate care and 25.1 percent receive inadequate care. FEMA uses the following steps to adjust total treatment costs from Schoenbaum for percentage of individuals who seek treatment and for prevalence.

$$Cost\ per\ person\ seeking\ treatment = Treatment\ cost\ per\ person^{45} * 0.41 * prevalence$$

For example,

$$\$623.63^{46} = (\$5{,}835.95 * 0.16) + (\$5{,}835.95 * 0.25.1) * 0.26$$

This methodology is applied to each length of time, adjusting for prevalence. The values provided by FEMA's Social Benefits Methodology Report have been normalized using the Consumer Pricing Index (CPI) Inflation Calculator,[47] and the costs for both severe and mild/moderate mental health problems over each time period are added together to provide a total treatment cost of $ 2,707 for 30 months.

44 Wang, Philip S., MD, DrPH; Lane, Michael, MS; Olfson, Mark, MD, MPH; Pincus, Harold A., MD; Wells, Kenneth B., MD, MPH; Kessler, Ronald C., PhD. 2005. Twelve-Month Use of Mental Health Services in the United States: Results from the National Comorbidity Survey Replication. Archives of General Psychiatry, v. 62, June.

A., MD; Wells, Kenneth B., MD, MPH; and Ronald C. Kessler, PhD. 2005. Twelve-Month Use of Mental Health Services in the United States: Results from the National Comorbidity Survey Replication. Archives of General Psychiatry, v. 62, June.

45 Schoenbaum, Michael; Butler, Brittany; Kataoka, Sheryl; Norquist, Grayson; Springgate, Benjamin; Sullivan, Greer; Duan, Naihua; Kessler, Ronald; Wells, Kenneth. 2009. Promoting Mental Health Recovery After Hurricanes Katrina and Rita: What Can Be Done at What Cost. Archives of General Psychiatry, Vol. 66, #8, August 2009.

46 Value not normalized to current dollars.

47 U.S. Bureau of Labor Statistics. Undated. CPI Inflation Calculator. [web page] Located at: http://www.bls.gov/data/inflation_calculator.htm.

Table 17 provides a summary of treatment costs in current dollars. These values are national figures and do not take into consideration local costs.

TABLE 17. COST OF TREATMENT[48] AFTER A DISASTER (30 MONTH DURATION), PER PERSON EXPECTED TO SEEK TREATMENT

Time after Disaster	Severe	Mild/Moderate	Total per person
7-12 months	$ 220.00	$ 691.27	$ 911.27
13-18 months	$ 256.66	$ 451.98	$ 708.64
19-24 months	$ 256.66	$ 372.22	$ 628.88
25-30 months	$ 218.89	$ 239.28	$ 458.17
Total			**$ 2,707**

Source: FEMA Updated Social Sustainability Methodology Report

3. Identify Impacted Population

Because the cost of treatment incorporates prevalence and course factors, the total number of residents in flooded buildings are considered impacted and included in the total population that may seek treatment. The cost of treatment per person over a 30-month period ($2,706.96) is applied to this population to determine treatment costs for mental stress and anxiety.

4.3.3 Assumptions

- Research analysis is limited to 30 months after a disaster. As such, estimated losses avoided are limited to this time period. Mental health avoided losses beyond two and a half years after a disaster, though expected, are not valued in this analysis.
- Benefits are calculated for only 41 percent of the impacted population because research indicates that only that portion of the population with mental health issues can be expected to seek treatment. This significantly lowers the calculated treatment costs and does not consider the full costs to society.
- Population growth is not considered in this analysis.
- These values are national figures and do not take local costs into consideration.

48 Costs normalized to 2015 dollars using the CPI calculator located at: http://data.bls.gov/cgi-bin/cpicalc.pl?cost1=623.63&year1=2008&year2=2015

4.4 Lost Productivity Consequence Analysis

Work productivity can be lost due to mental illness as described in research on the impact of psychiatric disorders on work loss days (Kessler and Frank, 1997). One report found that the average prevalence of psychiatric work loss days[49] is six days per month per 100 workers, and work cutback days[50] is 31 days per month per 100 workers.[51] Further research conducted by Kessler et al (2008) found that respondents with serious mental illness will experience a $16,306 reduction in a 12-month earning period compared to respondents without mental illness, and a study of 19 countries by the World Health Organization showed a lifetime 32 percent reduction in earnings for respondents with mental illness.[52] Historical impacts indicate that mental health issues will increase after a disaster, and this, paired with research related to lost productivity due to mental illness, indicates that economic productivity can be impacted by an increase in mental health issues post-disaster.[53]

4.4.1 Data Sources

- **Federal Emergency Management Agency's (FEMA) Final Sustainability Benefits Methodology Report (2012):**[54] This report provides a method to calculate benefits related to avoided lost productivity.
- **US Census Bureau American Community Survey (2014):** The average number of workers per household and persons per household are used to determine the number of impacted workers.
- **Flood depths:** Flood depths for each structure from the **Structure Damage and Contents Loss Exposure Analysis** are used to identify impacted buildings.
- **Structure Population:** The **Exposed Persons Analysis** provides the number of people expected to reside in impacted buildings.

49 A psychiatric work loss day is the complete inability to work or perform normal activities due to mental illness or its treatment.

50 Work cutback days is the reduced work activity due to mental illness or its treatment.

51 1: Kessler RC, Frank RG. The impact of psychiatric disorders on work loss days. Psychol Med. 1997 Jul; 27(4):861-73. PubMed PMID: 9234464.

52 Levinson, et al. 2010. Associations of Serious Mental Illness with Earnings: Results from the WHO World Mental Health Surveys. British Journal of Psychiatry. August; 197(2): 114–121. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2913273

53 Insel, Thomas. Assessing the Economic Costs of Serious Mental Illness. American Journal of Psychiatry. 165:6 June 2008. / Kessler et al. Individual and Societal Effects of Mental Disorders on Earnings on the United States: Results from the National Comorbidity Survey Replication. American Journal of Psychiatry. 165:6. June 2008.

54 Federal Emergency Management Agency. Final Sustainability Benefits Methodology Report. August 23, 2012.

4.4.2 Analysis Steps

1. Determine Value of Work Productivity

CRB Analysts researched several sources of literature related to lost productivity due to mental illness, and focused on a study in which Levinson et al (2010)[55] conducted research using the World Health Organization's Mental Health Surveys conducted in 19 countries. The study found that individuals in the United States with mental health illnesses experience as much as a 25.5 percent reduction in earnings. The national average for employment compensation in March 2015 was $33.49 per hour.[56] This, multiplied by the average number of hours worked per day (6.9),[57] produces a daily U.S. value of $231.08. Thus, a 25.5 percent reduction in earnings would equal a loss of $58.90 daily, or $1,767.77 monthly.

2. Determine Prevalence Rates

Post-disaster time periods are based on prevalence factors presented in Table 16 in the **Mental Stress and Anxiety Consequence Analysis**. The number of months of each time period after the disaster (Column 1 of Table 18) is applied to the monthly productivity loss ($1,767.77) to determine possible lost productivity for that time period. Prevalence factors from Schoenbaum (2009) are used to adjust productivity loss, as only a portion of the population will experience mental health impacts post-disaster. The prevalence factor is based on severe mental health issues because there is insufficient literature to document the impacts of mild/moderate mental health issues on productivity.[58]

TABLE 18. 30-MONTH LOSS IN PRODUCTIVITY PER WORKER, ATTRIBUTED TO SEVERE MENTAL HEALTH

Time after Disaster	Potential Productivity Loss due to Severe Mental Illness	Prevalence Factor in Impacted Population	Proportionate Productivity Loss Share per Worker in Impacted Population
1-12 months (12 mo.)	$21,213	6 percent	$1,273
13-18 months (6 mo.)	$10,607	7 percent	$742
19-24 months (6 mo.)	$10,607	7 percent	$742

55 Levinson, et al. 2010. Associations of Serious Mental Illness with Earnings: Results from the WHO World Mental Health Surveys. British Journal of Psychiatry. August; 197(2): 114–121. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2913273

56 Employer Costs for Employee Compensation. March 2015. United States Department of Labor, Bureau of Labor Statistics.

57 Average week hours of overtime of all employees. Web page. Located at: http://www.bls.gov/news.release/empsit.t18.htm

58 FEMA. 2014. Updated Social Benefits Methodology Report. December 18.

Time after Disaster	Potential Productivity Loss due to Severe Mental Illness	Prevalence Factor in Impacted Population	Proportionate Productivity Loss Share per Worker in Impacted Population
25-30 months (6 mo.)	$10,607	6 percent	$636
Total Productivity Loss per Worker			$3,394

For example,

$$(\$1{,}767.77\ per\ month * 12\ months) * 6\ percent = \$1{,}273$$

3. Identify Impacted Population

As prevalence is considered in the annual cost of lost productivity, the total population in residential and mixed use buildings that experience flooding are considered impacted for this analysis. The average number of persons per household (2.36) were used to determine number of households in Boston from population data. The average number of workers per household in Boston (1.4 workers) is applied to the number of households impacted to determine the number of wage earning residents who will experience flooding. The total lost productivity share per worker for 30 months ($3,394) is applied to the number of wage-earning residents who will experience flooding to value productivity losses avoided.

4.4.3 Assumptions

- Value is provided for the first 30 months only because there is insufficient literature available to analyze longer periods of time.
- Prevalence rates are based on severe mental issues because there is insufficient literature related the impacts of mild or moderate mental health problems on work productivity. Thus, results are considered conservative.
- Population growth is not considered in this analysis.
- Values are national figures and do not take into consideration local costs.

5 ECONOMY

Impacts to people, structures, infrastructure, and general interruption of normal activity as a result of climate-related hazards can also disrupt the broader Boston economy. Severe impacts can have regional, national, and even international consequences. As a result, CRB has sought to capture the potential impacts of business interruption within Boston due to coastal and riverine flooding with sea level rise. The business interruption consequence analysis, described below, uses the restoration time per building developed in the **Displacement Consequence Analysis** to estimate expected losses of sales and revenues (output loss), employment compensation, and jobs post-flood.

The business interruption analysis calculates direct output losses (sales and revenues) for the 10 percent, 1 percent, and 0.1 percent annual chance events, or frequencies, for three different sea level rise scenarios: 9 inches, 21 inches, and 36 inches. These losses are annualized and modeled with IMPLAN economic input-output software to estimate indirect and induced economic losses expected throughout Suffolk County. As such, results are presented as annualized for each sea level rise scenario only (individual results values are not presented). This methodology explains the process and approach performed by CRB Analysts to yield the results of each analysis.

Direct Impacts	Indirect Impacts	Induced Impacts
• The loss of sales and revenues (output), employment compensation, and employment due to business interruption. • Business interruption is calculated using restoration time.	• The impact of local industries buying goods and services from other local industries. The cycle of spending works its way backward through the supply chain until all money leaks from the local economy, such as through imports.	• The response by an economy to an initial change (direct effect) that occurs through re-spending of income received. Employee compensation funds are recirculated through household spending patterns.

FIGURE 4. ECONOMIC IMPACT DEFINITIONS

5.1 Business Interruption Consequence Analysis

The Business Interruption Consequence Analysis models existing economic relationships within Suffolk County, and the expected impacts to those relationships in a post-flood situation. These economic impacts are based on expected business interruption time, which is derived from restoration costs (refer to **Displacement Consequence Analysis** for an explanation of how business interruption times are calculated). Business interruption time can be used to calculate the expected direct output losses (sales and revenues) for an economic industry. Direct output losses are imported into input-output modeling software to estimate the effects of sales and revenues loss on relationships with other industries and spending patterns in the economy (generating indirect and induced output losses). While direct output losses are based on structures within Boston expected to flood, the economic modeling software models economic relationships throughout Suffolk County. Thus, business interruption consequence analysis results are expected economic impacts to the County economy. No broader effects (such as metropolitan area, state, national, or international) are considered. Due to this and other reasons described below, results of this analysis are expected to be conservatively low.

5.1.1 Data Sources

- **Hazus 2.1 Flood Technical Manual (TM), Direct Economic Losses Chapter 14** provides the principle calculation used to determine output loss.
- **Restoration time** identified through the **Displacement Consequence Analysis**.
- **Flood depths:** Flood depths for each structure from the **Structure Damage and Contents Loss Exposure Analysis** are used to identify impacted buildings.
- **2014 IMPLAN County Data for Suffolk County**. IMPLAN incorporates economic data from many sources, including the U.S. Bureau of Economic Analysis (BEA), the U.S. Bureau of Labor Statistics (BLS), and the U.S. Census Bureau. The dataset used provides localized economic industry data by zip code within Suffolk County, including output values (sales and revenues), labor income (employee and proprietor compensation), value added (contribution to national Gross Domestic Product), and employment (jobs).

5.1.2 Approach

The approach to calculate expected business interruption as a result of flood impacts is as follows:

1. Map PTYPEs to IMPLAN economic industries using a crosswalk, similar to the process used to map PTYPEs to Hazus occupancy classes described in the **Structure Damage and Contents Loss Consequence Analysis**. Due to the level of detail provided in the PTYPE occupancy descriptions, the crosswalk rarely identifies singular relationships between a PTYPE and an IMPLAN economic industry. To account for this, CRB analysts developed groups of PTYPES and economic industries that are related; these groupings varied by zip code, depending on the PTYPES and economic industries present within the area. Table 19 provides example groups for offices and retail space. CRB analysts developed one crosswalk per zip code in Suffolk County.

TABLE 19. EXAMPLE BUSINESS INTERRUPTION GROUPS – RETAIL AND COMMERCIAL BUILDINGS

Group	IMPLAN Code	IMPLAN Description	Ptype	Ptype Description
Retail	397	Retail - Furniture and home furnishings stores	319	STRIP CENTER /STORES
	398	Retail - Electronics and appliance stores	320	RETAIL /WHSL /SERVICE
	399	Retail - Building material and garden equipment and supplies stores	325	RETAIL STORE DETACHED
	400	Retail - Food and beverage stores	390	COMMERCIAL LAND
	401	Retail - Health and personal care stores	391	COM LAND (SECONDARY)
	402	Retail - Gasoline stores	950	RETAIL CONDO: EXEMPT
	403	Retail - Clothing and clothing accessories stores	357	RETAIL CONDO
	404	Retail - Sporting goods, hobby, musical instrument and book stores		
	405	Retail - General merchandise stores		
	406	Retail - Miscellaneous store retailers		
	407	Retail - Nonstore retailers		
	443	General and consumer goods rental except video tapes and discs		
	395	Wholesale Trade		
	396	Retail - Motor vehicle and parts dealers		
Commercial	415	Couriers and messengers	13	RES /COMMERCIAL USE
	427	Wired telecommunications carriers	25	RC: ONE RES UNIT
	432	Internet publishing and broadcasting and web search portals	26	RC: TWO RES UNITS
	437	Insurance carriers	27	RC: THREE RES UNITS
	438	Insurance agencies, brokerages, and related activities	31	COM /RES MULTI-USE
	445	Commercial and industrial machinery and equipment rental and leasing	340	OFFICE (ATTACHED)
	447	Legal services	343	OFFICE 1-2 STORY
	448	Accounting, tax preparation, bookkeeping, and payroll services	344	OFFICE 3-9 STORY

2. Calculate total average output per square foot for a group. CRB analysts added all square footage of PTYPEs in a group, and all output data for economic industries within a group, and developed an average annual and daily output per square foot for a group.

$$Total\ Average\ Ouput\ per\ Square\ Foot = Group\ Total\ Economic\ Output\ /\ Group\ Total\ Square\ Footage$$

3. Identify impacted structures within the various groups. Structures that are expected to incur restoration time (as identified through the **Displacement Consequence Analysis**) are eligible for direct business interruption consequences. The area of impacted square footage is necessary from eligible structures (those expected to incur restoration time); if the flood depth within a structure is less than 10 feet, it is assumed that only the first floor is flooded, and thus the square footage of the footprint is considered.

4. Calculate output losses. Hazus Flood TM provides calculations to evaluate the expected loss of industry output due to business interruptions; this calculation is presented below. CRB analysts made minor revisions to the original calculation, discussed in the Assumptions section.

$$Structure\ Output\ Loss = (Floor\ Area\ of\ Impacted\ Building) * (Group\ Output\ per\ SF\ per\ Day) * (Structure\ Restoration\ Time)$$

5. Distribute direct output losses among grouped economic industries. In order to input output losses into the IMPLAN software, output losses for structures within a group have to be distributed among the economic industries within the group. This is done by using each industry's contributing output and assigning a weighting factor based on the industry's contribution to the group's total output. The weighting factor determines how much of the group's total output loss is assigned to an industry (

6. Table 20). The reason for developing a weighting factor, rather than distributing total output loss equally across all contributing industries, is because each industry is not equally prevalent in the study area. Below is an example of this approach.

TABLE 20. EXAMPLE WEIGHTING FACTORS AS DEMONSTRATED BY THE RESTAURANT GROUP

Economic Industry	Annual Industry Output	Output Weighting Factor
Full-Service Restaurants	$388,000,000	0.53
Limited-Service Restaurants	$177,000,000	0.24
All other food and drinking places	$171,000,000	0.23
Total	$736,000,000	-

$$Industry\ Output\ Loss = Total\ Group\ Output\ Loss * Output\ Weighting\ Factor$$

So, if the impacted structures belonging to the Restaurant Group have a total output loss of $10,000,000, the output loss would be distributed to each industry as displayed below in Table 21.

TABLE 21. EXAMPLE OUTPUT LOSS DISTRIBUTION AMONG RESTAURANT INDUSTRIES

Economic Industry	Output Weighting Factor	Output Loss per Industry
Full-Service Restaurants	0.53	$5,300,000
Limited-Service Restaurants	0.24	$2,400,000
All other food and drinking places	0.23	$2,300,000
Total Group Output Loss	-	$10,000,000

7. Input direct output losses per industry in IMPLAN software, and model indirect and induced impacts within a zip code throughout the Suffolk County economy. IMPLAN software uses a combination of social accounting matrices and economic multipliers to estimate the result of changes or activities. The software reports estimated direct, indirect, and induced impacts for economic output, labor income, value added, and employment.

5.1.3 Assumptions and Avoidance of Benefit Duplication

Because there are many assumptions associated with the business interruption analysis, assumptions are organized by three categories: Crosswalk Development, Output Loss Calculations, and IMPLAN Modeling.

- Crosswalk Development
  - The crosswalk rarely identifies one to one relationships between a PTYPE and an IMPLAN economic industry. Instead, analysts must make assumptions and aggregate economic industries and PTYPEs into groups. Once such groups are formed, analysts assign each group an average value of output (sales and revenues) per square foot for the group based on local data.
  - In order to estimate Boston's expected business interruption consequences at a neighborhood level, the zip code is the basis of the crosswalk. CRB Analysts assumed

that average output values per square foot within a zip code are generally appropriate for buildings located within that zip code.

- Output Loss Calculations
  - Distributing output loss results amongst economic industries within a group using weight factors is necessary because it is inappropriate to assume that each economic industry within a family is equally prevalent in the study area. For example, it is not fair to assume that a 2,500 square foot computer technology store has the same output as a clothing store of the same size, even though both industries are in the retail family. By weighting industries based on actual output per square foot within the zip code, the expected damage to each industry is appropriately modified to reflect the approximate presence of the industry in the local economy.
  - Output loss calculations are based solely upon direct physical damages to buildings. As a result, results shown do not provide a logical connection to significant disaster impacts to services such as transportation or utilities. In addition, disruption is likely to occur to the entire structure for a period of time (for several reasons, to include power outage, MEP damage that impacts the entire structure, molding or other issues, and more), as opposed to only directly impacted floors. There is no currently available reliable research that could be located to estimate these impacts, and so they have been excluded from the evaluation. This is a limitation of the analysis and likely yields conservative results.
  - If the expected flood depth within the structure is less than ten feet, the building footprint is used to calculate output loss. In the case that expected flood depth is more than ten feet, CRB analysts assumed that some portion of the second story of the structure was inundated, and the square footage for the first two floors is considered.
  - Mixed use structures are assumed to have all non-residential space located on the lowest floors. See Section 3.0 Property for more on this.
  - The original output loss calculation provided by the Earthquake Technical Manual incorporates a recapture factor, which represents output losses that can be recouped to some extent by working overtime after an event. These recapture factors have not been included in the output loss calculation. The analysis assumes that, as soon as a business relocates or reopens after a disaster, it is able to return immediately to pre-storm output. Recapture factors are not appropriate for use because they do not consider opportunity costs.

- IMPLAN Modeling: IMPLAN input-output software is used in the analysis to identify indirect and induced economic losses that result from business interruption, and therefore serves to model the economic relationships present within the New York County economy. The below assumptions must be considered when observing the IMPLAN results:
    - The results display the economic impacts expected within Suffolk County as a result of expected output loss in a zip code. Therefore, these impacts are considered to be conservative, as the local economy for the study area has economic linkages that impact areas far beyond Suffolk County.
    - IMPLAN does not account for price elasticities or changes in consumer/industry behavior based on a direct effect, such as changes in spending patterns within sectors not related directly to activity changes.
    - Seasonal variation in economic output of various sectors included in the analysis was not considered due to data limitations. Results are presented in 2016 dollars.

6 CONSEQUENCE ANALYSIS DATA

CRB Analysts imported the results of the CRB consequence analyses into ArcGIS to facilitate data transfer and use. The consequence analysis results dataset is a point-file dataset, and is meant to accompany the general building stock. Note that any changes to the CRB building footprint dataset or the general building stock should be carried over into consequence analysis results during future evaluations in order to maintain data consistency and improve results fidelity over time. Table 22 provides a list of the attributes for one sea level rise scenario; these attributes are repeated within the ArcGIS data for each sea level rise scenario and are appropriately labeled as such.

TABLE 22. CRB CONSEQUENCE ANALYSIS ATTRIBUTES AND DESCRIPTION WITHIN EACH STUDIED SEA LEVEL RISE SCENARIO

Attribute	Field Name	Description
CRB ID	CRB_BLDGID	Building ID developed by CRB analysts to facilitate data management and QAQC.
Latitude	Latitude	Reference point of the building centroid.
Longitude	Longitude	Reference point of the building centroid.
PTYPE	TempPTYPE	Building use.
10% Flooded	Flooded_9in_10per	Notes if the building is located within the inundation area of the 10% flood extent.
10% Flood Depth	NT9in_10per_AEP_Flood_Depth	The expected flood depth in the structure for the 10% flood event. Determined by subtracting water surface elevations from the building elevation.
10% Percent Building Loss	NT9in_10per_AEP_Building_Loss	Percent building loss to determine the damage state for the 10% flood event. Based on occupancy type and flood depth.
10% Building Damage Costs	NT9in_10per_AEP_Building_Loss2	Expected damage costs for the structure for the 10% flood event.
10% Percent Contents Loss	NT9in_10per_AEP_Contents_Loss	Percent contents loss for the structure for the 10% flood event. Based on occupancy type and flood depth.
10% Building Contents Loss	NT9in_10per_AEP_Contents	Expected contents losses for the structure for the 10% flood event.
10% Days Relocation	NT9in_10per_AEP_Days_Relocation	Expected relocation time for the structure for the 10% flood event, based on occupancy type and flood depth.

Attribute	Field Name	Description
10% Days Relocation Cost	NT9in_10per_AEP_Relocation_Cost	Expected relocation costs for structure occupant and business relocation for the 10% flood event.
10% Restoration Time	NT9in_10per_Days_Restoration	Method 1 to estimate restoration time for the 10% flood event.
10% ELOF Test	ELOF_TEST_10per_AEP	Method 2 to estimate restoration time for the 10% flood event. Used in the CRB Analysis.
10% Business Interruption SF	NT9in_10per_AEP_ELOF_SF	Square footage analysis to determine business interruption results for the 10% flood event.
10% ELOF Impact	NT9in_10per_ELOF_Impact	Restoration Time multiplied by the Business Interruption square footage for the 10% flood event.
2% Flooded	NT9in_2per_flooded	Notes if the building is located within the inundation area of the 2% flood extent.
2% Flood Depth	NT9in_2per_AEP_flood_depth	The expected flood depth in the structure for the 2% flood event. Determined by subtracting water surface elevations from the building elevation.
2% Percent Building Loss	NT9in_2per_AEP_per_Building_Loss	Percent building loss to determine the damage state for the 2% flood event. Based on occupancy type and flood depth.
2% Building Damage Costs	NT9in_2per_AEP_Building	Expected damage costs for the structure for the 2% flood event.
2% Percent Contents Loss	NT9in_2per_AEP_per_Contents_Loss	Percent contents loss for the structure for the 2% flood event. Based on occupancy type and flood depth.
2% Building Contents Loss	NT9in_2per_AEPContents	Expected contents losses for the structure for the 2% flood event.
2% Days Relocation	NT9in_2per_AEP_Relocation	Expected relocation time for the structure for the 2% flood event, based on occupancy type and flood depth.
2% Days Relocation Cost	NT9in_2per_AEP_Relocation_Cost2	Expected relocation costs for structure occupant and business relocation for the 2% flood event.
2% Restoration Time	NT9in_2per_Days_Restoration	Method 1 to estimate restoration time for the 2% flood event.
2% ELOF Test	ELOF_TEST_2per_AEP	Method 2 to estimate restoration time for the 2% flood event. Used in the CRB Analysis.
2% Business Interruption SF	NT9in_2per_AEP_ELOF_SF	Square footage analysis to determine business interruption results for the 2% flood event.

Attribute	Field Name	Description
2% ELOF Impact	NT9in_2per_ELOF_Impact	Restoration Time multiplied by the Business Interruption square footage for the 2% flood event.
1% Flooded	NT9in_1per_flooded	Notes if the building is located within the inundation area of the 1% flood extent.
1% Flood Depth	NT9in_1per_AEP_flood_depth	The expected flood depth in the structure for the 1% flood event. Determined by subtracting water surface elevations from the building elevation.
1% Percent Building Loss	NT9in_1per_AEP_per_Building_Loss	Percent building loss to determine the damage state for the 1% flood event. Based on occupancy type and flood depth.
1% Building Damage Costs	NT9in_1per_AEP_Building	Expected damage costs for the structure for the 1% flood event.
1% Percent Contents Loss	NT9in_1per_AEP_per_Contents_Loss	Percent contents loss for the structure for the 1% flood event. Based on occupancy type and flood depth.
1% Building Contents Loss	NT9in1per_AEP_Contents	Expected contents losses for the structure for the 1% flood event.
1% Days Relocation	NT9in_1per_AEP_Days_Relocation	Expected relocation time for the structure for the 1% flood event, based on occupancy type and flood depth.
1% Days Relocation Cost	NT9in_1per_AEP_Relocation_Cost	Expected relocation costs for structure occupant and business relocation for the 1% flood event.
1% Restoration Time	NT9in_1per_Days_Restoration	Method 1 to estimate restoration time for the 1% flood event.
1% ELOF Test	ELOF_TEST_1per_AEP	Method 2 to estimate restoration time for the 1% flood event. Used in the CRB Analysis.
1% Business Interruption SF	NT9in_1per_AEP_ELOF_SF	Square footage analysis to determine business interruption results for the 1% flood event.
1% ELOF Impact	NT9in_1per_ELOF_Impact	Restoration Time multiplied by the Business Interruption square footage for the 1% flood event.
0.1% Flooded	NT9in_01per_flooded	Notes if the building is located within the inundation area of the 0.1% flood extent.
0.1% Flood Depth	NT9in_01per_AEP_Flood_Depth	The expected flood depth in the structure for the 0.1% flood event. Determined by subtracting water surface elevations from the building elevation.

Attribute	Field Name	Description
0.1% Percent Building Loss	NT9in_01per_AEP_per_Building_Loss	Percent building loss to determine the damage state for the 0.1% flood event. Based on occupancy type and flood depth.
0.1% Building Damage Costs	NT9in_01per_AEP_Building	Expected damage costs for the structure for the 0.1% flood event.
0.1% Percent Contents Loss	NT9in_01per_AEP_per_Contents_Loss	Percent contents loss for the structure for the 0.1% flood event. Based on occupancy type and flood depth.
0.1% Building Contents Loss	NT9in_01per_AEP_Contents	Expected contents losses for the structure for the 0.1% flood event.
0.1% Days Relocation	NT9in_01per_AEP_Days_Relocation	Expected relocation time for the structure for the 0.1% flood event, based on occupancy type and flood depth.
0.1% Days Relocation Cost	NT9in_01per_AEP_Relocation_Cost	Expected relocation costs for structure occupant and business relocation for the 0.1% flood event.
0.1% Restoration Time	NT9in_01per_Days_Restoration	Method 1 to estimate restoration time for the 0.1% flood event.
0.1% ELOF Test	ELOF_TEST_01per_AEP	Method 2 to estimate restoration time for the 0.1% flood event. Used in the CRB Analysis.
0.1% Business Interruption SF	NT9in_01per_AEP_ELOF_SF	Square footage analysis to determine business interruption results for the 0.1% flood event.
0.1% ELOF Impact	NT9in_01per_ELOF_Impact	Restoration Time multiplied by the Business Interruption square footage for the 0.1% flood event.
10% Mental Stress and Anxiety	NT10per_AEP_Mental_Stress	Expected treatment costs of mental stress for residents of structures impacted by the 10% flood event.
10% Lost Productivity	NT10per_AEP_Lost_Productivity	Expected costs of lost work days due to mental stress related to 10% flood event impacts.
10% Shelter Needs	NT10per_AEP_Shelter_Needs	Number of residents within buildings impacted by the 10% event expected to require shelter.
2% Mental Stress and Anxiety	NT2per_AEP_Mental_Stress	Expected treatment costs of mental stress for residents of structures impacted by the 2% flood event.
2% Lost Productivity	NT2per_AEP_Lost_Productivity	Expected costs of lost work days due to mental stress related to 2% flood event impacts.
2% Shelter Needs	NT2per_AEP_Shelter_Needs	Number of residents within buildings impacted by the 2% event expected to require shelter.

Attribute	Field Name	Description
1% Mental Stress and Anxiety	NT1per_AEP_Mental_Stress2	Expected treatment costs of mental stress for residents of structures impacted by the 1% flood event.
1% Lost Productivity	NT1per_AEP_Lost_Productivity	Expected costs of lost work days due to mental stress related to 1% flood event impacts.
1% Shelter Needs	NT1per_AEP_Shelter_Needs	Number of residents within buildings impacted by the 1% event expected to require shelter.
0.1% Mental Stress and Anxiety	NT01per_AEP_Mental_Stress	Expected treatment costs of mental stress for residents of structures impacted by the 0.1% flood event.
0.1% Lost Productivity	NT01per_AEP_Lost_Productivity	Expected costs of lost work days due to mental stress related to 0.1% flood event impacts.
0.1% Shelter Needs	NT01per_AEP_Shelter_Needs	Number of residents within buildings impacted by the 0.1% event expected to require shelter.
10% Annualized Building Damage	NT10per_Ann_Bldg_	Annualized building damage expected for the 10% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
10% Annualized Contents Loss	NT10per_Ann_Contents	Annualized contents and inventory loss expected for the 10% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
10% Annualized Displacement	NT10per_Ann_Displacement_	Annualized displacement costs expected for the 10% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
10% Annualized Mental Stress	NT10per_Ann_Mental_Stress	Annualized mental stress treatment costs expected for the 10% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
10% Annualized Lost Productivity	NT10per_Ann_Lost_Productivity	Annualized lost productivity expected for the 10% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
2% Annualized Building Damage	NT2per_Ann_Bldg	Annualized building damage expected for the 2% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
2% Annualized Contents Loss	NT2per_Ann_Contents	Annualized contents and inventory loss expected for the 2% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.

Attribute	Field Name	Description
2% Annualized Displacement	NT2per_Ann_Displacement	Annualized displacement costs expected for the 2% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
2% Annualized Mental Stress	NT2per_Ann_Mental_Stress	Annualized mental stress treatment costs expected for the 2% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
2% Annualized Lost Productivity	NT2per_Ann_Lost_Productivity	Annualized lost productivity expected for the 2% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
1% Annualized Building Damage	NT1per_Ann_Bldg	Annualized building damage expected for the 1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
1% Annualized Contents Loss	NT1per_Ann_Contents	Annualized contents and inventory loss expected for the 1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
1% Annualized Displacement	NT1per_Ann_Displacement	Annualized displacement costs expected for the 1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
1% Annualized Mental Stress	NT1per_Ann_Mental_Stress	Annualized mental stress treatment costs expected for the 1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
1% Annualized Lost Productivity	NT1per_Ann_Lost_Productivity	Annualized lost productivity expected for the 1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
0.1% Annualized Building Damage	NT01per_Ann_Bldg	Annualized building damage expected for the 0.1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
0.1% Annualized Contents Loss	NT01per_Ann_Contents	Annualized contents and inventory loss expected for the 0.1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
0.1% Annualized Displacement	NT01per_Ann_Displacement	Annualized displacement costs expected for the 0.1% annual chance event. Calculated by

Attribute	Field Name	Description
		multiplying expected one-time damage costs by the probability of occurrence.
0.1% Annualized Mental Stress	NT01per_Mental_Stress	Annualized mental stress treatment costs expected for the 0.1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
0.1% Annualized Lost Productivity	NT01per_Lost_Productivity	Annualized lost productivity expected for the 0.1% annual chance event. Calculated by multiplying expected one-time damage costs by the probability of occurrence.
Total Annualized Structure and Contents	Total_Annualized_Structure_and_Contents_Losses	Total annualized structure and contents losses expected for the sea level rise scenario. Developed by adding expected annualized structure and contents losses for the four frequencies analyzed.
Total Annualized Loss of Service	Total_Annualized_Loss_of_Service__Function	Total annualized loss of service expected for the sea level rise scenario. Developed by adding expected annualized loss of service values for the four frequencies analyzed.
Total Annualized Structure, Content, and Relocation Costs	Total_Annualized_Structure_Content_and_Relocation_Losses	Total annualized structure, contents, and relocation losses expected for the sea level rise scenario (total property consequences). Developed by adding expected property consequences for the four frequencies analyzed.
Total Annualized Relocation	Total_Annualized_Relocation	Total annualized relocation costs expected for the sea level rise scenario. Deveoped by adding expected annualized results for the four frequencies analysed.
Total Annualized Stress Factor Losses	Total_Annualized_Stress_Factor_Losses	Total annualized mental stress and lost productivity costs expected for the sea level rise scenario. Developed by adding expected mental stress and lost productivity costs for the four frequencies analyzed.
Total Annualized Mental Stress	Total_Annualized_Mental_Stress	Total annualized mental stress costs expected for the sea level rise scenario. Developed by adding expected mental stress costs for the four frequencies analyzed.
Total Annualized Lost Productivity	Total_Annualized_Lost_Productivity	Total annualized lost productivity costs expected for the sea level rise scenario. Developed by adding expected lost productivity costs for the four frequencies analyzed.

Attribute	Field Name	Description
Total Annualized Losses	Total_Annualized_Losses	Total annualized losses for the sea level rise scenario. Developed by adding all expected consequences for the four frequencies analyzed.
Neighborhood	Neighborhood	Neighborhood the structure is located within, based on Martin’s neighborhood boundaries.